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An Exploration of High Level Language Comprehension Deficits and the Factors Influencing Them Following Blast Exposure in Afghanistan and Iraq War Veterans

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BY

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Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Health Sciences

Department of Interprofessional Health Sciences and Health Administration

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Running head: bTBI AND COMPREHENSION OF HIGH LEVEL LANGUAGE

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Abstract

Our servicemen and women are facing challenges with reintegration into civilian life as noted by the high levels of homelessness, unemployment, and suicide. Behavioral aspects and PTSD have been the focus of these problems. There may be additional factors that negatively impact successful reintegration. There may be weaknesses in communication skills such as auditory processing deficits and higher-level language deficits secondary to blast exposure. Twelve veterans with history of blast exposure and six veteran controls were compared in areas of auditory processing, higher-level language skills (inferencing, ambiguity, figurative language), and attention, memory, and visual processing speed. Correlations with auditory processing and higher-level language and cognitive skills were also explored. Results demonstrated significance with attention ($p = 0.001$), time compressed sentences ($p = 0.02$), and for the veterans who wear not wearing their helmets at the time of blast exposure demonstrated additional significance with inferencing ($p = 0.04$), and auditory figure ground ($p = 0.05$). Weaknesses were noted with competing words ($p = 0.08$) and multiple meanings ($p = 0.08$). Strong and moderate correlations were observed with veterans who were not wearing their upgraded helmet at the time of blast exposure. Results suggest a need to include speech pathologists as part of the diagnostic team for our returning servicemen that were exposed to blasts,

especially if they were not wearing their upgraded helmet at the time of exposure, so as to rule out any deficits with higher-level language skills, or auditory processing deficits.

Chapter I

INTRODUCTION

Thomas, an Iraqi war veteran, went to a VA hospital for treatment for knee injury obtained from a blast exposure while deployed. Through the interview process it was revealed that Tom was having difficulty reintegrating into society. He would forget job interviews, oversleep, had headaches, and was drinking alcohol regularly. Tom had not had post trauma screenings while deployed (Batten & Pollack, 2008). This story is not uncommon. Approximately 1.7 million soldiers from three theaters have been deployed during the war on terror. They are Operation Iraqi Freedom (OIF), 2001-December 2011, Operation Enduring Freedom (OEF) in Afghanistan, 2001 to present, and Operation New Dawn (OND), 2003 to present. Fifteen to nineteen percent of these soldiers have returned with blast related injuries. This accounts for approximately (Hoge, et al., 2008) 255,000 – 323,000 soldiers. The DoD (2016) - estimated that 20%, or 348,000 OEF/OIF soldiers have sustained a TBI during deployment, which mostly (82%) consist of mTBI's. In this war there are significantly more injuries from explosions than from gunshots.

These service members demonstrate deficits in working memory, attention, sensory (auditory and visual), and auditory processing. These deficits are correlated with language skills. Working memory and language are correlated. Research demonstrates that decreased working memory capacity decreased complex sentence comprehension (Baddeley, 2003, Moser, Fridriksson, & Healy, 2007). Attention and language are correlated. Poor attention or decreased ability to divide attention limits ability to learn new information, follow directions, and follow conversation in social situations (Baddeley, 2003, Kristensen, Petersson, & Hagoort, 2013). Auditory attention and sentence comprehension activate same brain networks suggesting both are interactive. Auditory processing and language are connected. Research by Tun, Williams, Small, & Hafter (2012) reveal that auditory processing is needed for language comprehension. Dual Sensory Impairment-vision and hearing are connected with language, (Lew, Pogada, Baker, et al., 2011, Lew, Garvert, Pogoda, et al., 2009). Facial expressions, gestures and other nonverbal cues may be missed with visual perceptual impairment and hearing loss would create difficulty with interpreting the tone of a person's voice. Tone facilitates a person's ability to interpret a speaker's mood or intent.

Current literature on language deficits with bTBI is limited. Parrish, Roth, Roberts and Davie, (2009) found deficits with word finding and recall of names. There was no report of auditory comprehension functions. Mild TBI has the same medical criteria as bTBI with the exception on how the brain injury is acquired. Literature review on language skills with mTBI revealed the following in the area of comprehension: trends or weaknesses on cognitive flexibility such as comprehension of complex language, which includes inferences, interpreting figurative language, and ambiguity (Whelan and Murdoch, 2006; Barwood and Murdoch, 2013). Whelan and Murdoch, 2006 examined only five subjects, which identified some trends. The trends demonstrated weaknesses on tasks that would require cognitive flexibility such as comprehension of complex language (i.e. inferences, interpreting figurative language, and ambiguity). Whelan, Murdoch, and Bellamy (2007) using a single subject study used both cognitive assessment tools and language assessments, including high-level linguistic assessments such as the *Test of Language Competence-Expanded.* The authors reported cognitive-communication deficits such as attention, lexical access, complex lexical-semantic manipulation both in comprehension and expression, organization and self-monitoring of responses. Wong, Murdoch, & Whelan (2010) examined only four mTBI subjects, and found one subject scored 2.0 SD below the norm on the *Token Test*. Finally, Barwood and Murdoch (2013), examined sixteen mTBI subjects and compared to a control group. The results demonstrated significant findings, $p<0.02$, in comprehension of ambiguous sentences, comprehension of inferences, and figurative language. These subtle higher order language deficits can negatively influence the veteran's daily living communicative activities, and further disrupt their abilities to reintegrate into society.

Background

The "War on Terror" began in 2001 with two separate theaters. The first was called Operation Iraqi Freedom (OIF). This conflict ended in December 2011. The second, Operation Enduring Freedom (OEF), which is in Afghanistan, and a third Operation New Dawn (OND), are both still taking place. Improvised explosive devices are the most common weapon used by the Iraq and Afghanistan enemy. Fortunately, due to the improvement of military armor, specifically the chest gear and helmet, more of our soldiers are surviving these blasts (Moore & Jaffee, 2010). However, as a result there are now more soldiers who are suffering from mild head injuries (mTBI), or concussions secondary to these blasts. The coin term for this injury is blast TBI or bTBI, or barotrauma. Many of the soldiers are exposed to multiple bTBI's. Symptoms as a result of mTBI are referred to as post concussive syndrome (PCS). Though many soldiers will recover within a few months, some will continue to have disabling symptoms that negatively affect their quality of life (Snell & Halter, 2010). Blast Injury has become known as the "signature injury" of these current military conflicts.

Most literature has examined the cognitive deficits these veterans exhibit such as memory deficits, attention deficits, and executive functioning

(Belanger, 2009; Hicks, 2010; Kennedy, 2010). Language impairments have been researched with the civilian mTBI population (Whelan, & Murdoch, 2006; King, Hough, Vos,et al., 2006; Raskin, & Rearick, 1996). There is minimal data on language deficits with bTBI. The purpose of this paper is to first, define and describe bTBI population, examine comorbid disorders, such as posttraumatic stress disorder (PTSD), and examine the literature for reported language deficits. Secondly, post-concussion syndrome (PCS), attention deficits correlated with PCS, and anatomical events that occur in mTBI and bTBI will be addressed. A parallel between the PCS literature and bTBI literature will be drawn. Finally, a literature gap will be identified and future research needs.

Operational definitions are essential for comparison of literature. A blast is defined as an explosion in the atmosphere, which is the release of energy, which produces a pressure wave. The pressure wave has an under-pressure component, which may exceed the critical tensile strength of body tissue’s fluid component. The blast waves are reflected off other objects in the area and create a combination of a reflective wave in addition to the initial pressure wave, which can intensify the pressure field. A blast injury is defined as an injury related to the shock-wave overpressure and under-pressure. Secondary injuries may result from fragments or shrapnel, or from throwing the soldier, or from thermal or toxic detonations (Moore & Jaffee, 2010). There is more than one type of blast injury.

There are four categories for blast injuries: primary blast injury, physical penetration, tertiary blast injury, and quaternary blast injury. Primary blast injury is the result of rapid changes in atmospheric pressure that is created by the blast wave. Air filled cavities, such as the lungs or middle ear, are most susceptible to damage (Snell & Halter, 2010). This may result in the development of cavitations. This is the formation of cavities in a body tissue or an organ, for example those cavities that form in the lung as a result of tuberculosis (Moore & Jaffee, 2010). Physical penetration injuries refer to explosive device fragments or other object projectiles caused by the blast that enter the head. Tertiary blast injury refers to the injury as a result of being thrown, pushed or shoved into another object. Injuries from burns or inhalation of hot explosive gases are quaternary blast injuries (Snell & Halter). What is The Department of Defense's criteria that defines a blast injury and what is the prevalence of our soldiers sustaining a blast injury?

Blast TBI Diagnosis Criteria.

The Department of Defense's (2009) criteria for a mTBI is as follows: Loss of consciousness 0-30 minutes; Alteration of consciousness/mental state - a moment up to 24 hours; Post-traumatic amnesia – 0-1 day' Glasgow Coma Scale (best available score in first 24 hours) – 13-15. It is estimated that 20%, or 300,000 OEF/OIF soldiers have sustained a TBI during deployment, which mostly consist of mTBI's (Department of Veterans Affairs Health

Services Research & Development Service, 2009). Drake et at. (2010) screened 7909 marines between the years of 2004 and 2006 for positive occurrence of traumatic brain injury. Of these marines 23% (*n* = 1799) reported sustaining a physical injury. Of the 1799, 27.9% were reported to be secondary to a blast injury (*n* = 395). The Armed Forces Health Surveillance Center reported approximately 135,000 military service members were diagnosed with TBI between January of 2003 and January of 2010 (Graner, Oakes, French & Riedy, 2013). How is a bTBI identified?

Initially, there was some argument over whether these soldiers truly present with brain injuries, or where their symptoms are side effects from post-traumatic stress disorder. mTBI's are known to not show alteration in brain structure with CT, or with traditional MRI's (Graner, Oakes, French & Riedy, 2013). A research study by Peskind, et al. (2011) used PET imaging to examine 12 Iraq War veterans with mTBI from repetitive blast-trauma with and without PTSD. Their findings found that there was a decrease in cerebral metabolic rate of glucose in the cerebellum, vermis, pons and medial temporal lobe. These findings suggested that PTSD was not a factor in the symptoms associated with bTBI. Diffusion tensor imaging (DTI) is a more advanced form of MRI that is more sensitive to axonal injuries as it looks at subcortical white matter. Will DTI reveal brain damage in bTBI subjects?

Mac Donald, et al. (2011) used DTI to scan 63 US soldiers with a diagnosis of bTBI within 90 days post injury. These soldiers had been exposed to a primary blast injury, plus a second category of blast injury, such as trajectory. Twenty-one soldiers with no diagnosis of bTBI, but were exposed to a primary blast, served as controls. Results revealed abnormalities in the middle cerebellar peduncles ($p<0.001$), cingulum bundles ($p=0.002$), and right orbitofrontal white matter ($p=0.007$). Animal studies (swine, monkeys, and rats) all revealed neuronal changes in the white matter after exposure to blast waves (Bauman, et al., 2009; Lu, et al., 2012; Vandevord, Bolander, Sajja, Hay, &Bir, 2012). The Purkinje neurons in the cerebellum and pyramidal neurons in the hippocampus were noted to be the most vulnerable to blast overpressure in monkeys (Lu, et al., 2012). A more recent study of post-mortem autopsies revealed distinct differences between soldiers with blast exposure and a control group of brains. Shively et al. (2016) examined five brain specimens of soldiers who had died shortly after a severe blast exposure. They compared these brains with non-military brains with no history of blast exposure but had either chronic impact TBI or chronic exposure to opiates. All five of the blast exposed brains revealed astroglial scarring in the subpial glial plate, grey/white matter junctions and structures lining the ventricles as well as penetrating cortical blood vessels. This specific pattern of scarring may be unique to chronic blast exposure and it lines up with the general principles of blast biophysics. Post-concussion syndrome is more robust in explaining the neurological damages from repeated mTBI's.

The most common cause of a Post Concussive Syndrome (PCS) is repeated concussions occurred during a contact sport activity such as soccer or boxing. The anatomical structure called the fornix is susceptible to damage from a concussion. The fornix is half-way under the Corpus Collosum. The fornix is a white matter structure that is important for out-put from the hippocampus. The fornix is connected with the mammillary body and septum, but is loosely connected to the septum pellucilum. The anatomical position and loose connections is what portrays this structure as "a delicate" structure (Bigler, 2008).

Are there common neurological structures affected by a concussion? Bayly, et al. (2005) was addressing this question in his study. Bayly, et al. studied MRI's of subjects who the authors subjected to a head fall of 2 cm. MRI's where taken before and immediately after the drop. The authors stated that this movement was approximately 10-15% of the acceleration required for a soccer player who was "heading a ball".

The authors recorded the following effects upon the brain. The brain rotated backward and upward around the base of the brain. This is connected by the dural rings. Structures such as the distal internal carotid arteries, the optic and oculomotor nerves, olfactory tracts and other structures pass through the dural rings. The anterior portion of the brain is compressed and the posterior portion of the brain is stretched. The compression of the superior-frontal surface is against the top of the cranial vault. The brain elongated as the inertia pulls the brain backward and clockwise. Now the brainstem structures shortened and experienced shearing, while the posterior and inferior parts of the brain continued to rotate downward and forward.

Another research team, Viano, et al. (2005), also wanted to exam the cranial structures of the brain affected by a concussion. They examined NFL football players who had experienced a concussion on the field. The authors did this by simulating the cranial movement of the impact that was identified on video tapes of the incidents. What the authors found was that the initial impact occurred in the temporal lobe adjacent to the impact. Most of the shearing had occurred in the fornix, midbrain and corpus callosum. They also reported 4-5 mm displacement of the hippocampus, caudate, amygdale, anterior commissure, and midbrain. It is important to note that the medial temporal lobe and midbrain are close in proximity to each other.

Zhang, Heier, Zimmerman, Jordan, and Ulug (2006) used diffusion tensor imaging, a more sensitive MRI technique, to examine 32 professional boxers. All of the boxers demonstrated some white matter abnormalities, and seven of these boxers demonstrated significant white matter abnormalities. Most of the abnormalities were at the level of the corpus callosum, which correlates with Viano et al. (2005) study. This also is consistent with a study completed by Chappell, et al. (2006). Chappell, et al. (2006) studied 81 professional boxers using DTI methods and found abnormalities in the white matter. Omalu, et al. (2005) and Bigler, (2004) both compared autopsies of brains that had sustained concussions with their MRI's. Both studies found hemorrhagic lesions.

PET scans are another method to assess brain function, but symptoms may not always be exposed due to different task demands on each subject. For example, Chen, Kareken, Fastenau, Trexler, and Hutchins (2003) examined five subjects who had sustained a concussion. Four of these subjects presented with PPCS neurobehavioral symptoms but no abnormalities were revealed in a PET scan until the subjects were asked to perform a spatial working memory task. When asked to perform this task prefrontal cortex abnormalities were observed. Bernstein (2002) used evoked responses with subjects who had a history of concussions but no neurobehavioral symptoms. When these subjects were presented with a multi-task that required both auditory and visual discrimination skills they performed significantly different from the control group. Umile, Sandel, Alavi, Terry, and Plotkin (2002) used PET scans and neurocognitive testing to demonstrate that mTBI subjects demonstrate temporal lobe damage and memory deficits. These studies demonstrate that the abnormalities these subjects present with may be skill specific.

Assessing brain damage can also be obtained by assessing biochemical changes in the neurotransmitter disruption. Zetterberg, et al. (2006) studied cerebrospinal fluid in 14 armature boxers 7-10 days and 3 months post a boxing match and compared to a group of controls that had no physical contact events. The findings revealed neuronal injury byproducts in the cerebrospinal fluid correlated with the number of hits to the head during a fight without knock outs. Ost, et al. (2006) correlated a microtubular binding protein, tau, found in cerebral spinal fluid with the severity of TBI, so therefore this protein could be used as a marker of white mater injury.

MRI's, DTI's, PET scans and biochemical changes are all methods used to examine neurological changes from concussions. Another way to predict if a subject will suffer from post-concussion symptoms is by the examination of the peri-vascular spaces. Mild TBI's have demonstrated dilated peri-vascular space changes, white matter volume changes, and chemical composition changes (de la Plata, et al. (2007). Konsman, Drukarch, & Van Dam (2007) also reported perivascular inflammation and hemosiderin deposits in the peri-vascular to be markers of white matter injury.

How do these abnormalities correlate with neurobehavioral symptoms? Bigler (2008) reported how anatomical changes that occur from the rotational force that occurs from compression that is correlated with concussion symptoms. Bigler (2008) stated that slight changes in the upper brainstem and reticular activating system will affect consciousness. Mechanical compression of the perirhinal and entorhinal cortices will affect input and or output to the hippocampus through the fornix and the connection with the anterior thalamus and cingulated. The medial temporal lobe and basal forebrain is associated with emotional regulation. Stretching of the internal carotid artery is associated with posttraumatic migraines. The symptom of fatigue is associated with hormonal changes from the disruption of hypothalamic-pituitary area. Speed of processing is slowed after a concussion. This is correlated to the compromise of the integrity of white matter pathways. Long-coursing axons are more vulnerable for inter-hemispheric connections (Cecil, et al. 1998), such as the corpus callosum and anterior commissure. Finally, Autopsy studies found axonal injury in the fornix (Blumbergs, 1994; Viano, 2005). The fornix is a white matter structure that contains projecting axons from the hippocampus. The hippocampus is important for memory. Therefore, disruption in the fronix integrity may cause the disruption in short term memory (Bigler, 2008).

Why is there inconsistency in the research data? First, everyone has different thresholds for how many concussion occurrences needed before lasting deficits are exhibited (Zhu, Prange, & Margulies, 2006), and no two subjects are the same. In addition, poor research designs such as small sample numbers, samples of convenience and litigation bias, which confounds research, are all research limitations. Large subject groups can also affect research results in that individual subject symptoms can be washed out of the total group results. In addition, many of the studies fail to control for hearing loss, which may affect test results. Finally, lack of cohesiveness with terminology, and operational definitions can affect the consistency of research data.

In summary the vulnerability of the upper brainstem, hypothalamic-pituitary axis, medial temporal lobe, basal forebrain, long-coursing white matter fibers (corpus collosum and fornix) are anatomical regions of the brain associated with post concussive symptoms. Still most military personnel are diagnosed through neurocognitive assessments rather than imaging.

Functional Diagnostic Criteria of Blast TBI.

Most studies for bTBI look at neurocognitive symptoms. Some of the symptoms reported are memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012). The Veterans Affairs/Department of Defense (2009) list the following neurocognitive areas this population may exhibit deficits in: attention, concentration, memory, speed of processing, judgment, and executive function. Executive function includes problem solving, planning, organization, and mental flexibility (French & Parkinson, 2008). Is there similarities in the bTBI and mTBI cognitive impairments?

Luethcke, Craig, Morrow, and Isler (2011) compared cognitive and psychological symptoms between bTBI and non-blast mTBI subjects. They found very little differences between the two groups in the first 72 hours after injuries. The non-blast group lost consciousness more frequently, had a longer duration of unconsciousness and initially experienced more balance problems, nausea, and vomiting. No differences were found between the two groups in regards to psychological symptoms. Cognitive performance revealed no differences in the subject's speed of response or accuracy. No other between differences could be calculated due to limited sample size. The author's suggestion was to repeat this study with a larger sample size. Since research is lacking with military subjects we can turn to the concussion literature, which is the closest in similar symptoms and findings.

Sports literature has addressed the effects of multiple and single concussions on cognitive areas. A meta-analysis completed by Belanger, Speigel, and Vanderploeg (2009) examined the literature on this subject from 1970 through 2009. Out of 123 studies, only eight met their criteria. The authors were specifically interested in the effect sizes by cognitive domain and overall cognitive function. There results revealed the overall effect size on neuropsychological performance was 0.06 and for specific cognitive domains it was found that only executive functions and delayed memory had statistical significance with effective sizes of d=0.24; d=0.16, respectfully. These are small to medium in size. These studies reported an average of two to three concussions per subject. Our veterans are typically exposed to more occurrences of blasts than two or three.

In summary, the literature identifies common neurocognitive symptoms in both the blast mTBI group and the non-blast mTBI group. These symptoms consist of memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012), and deficits in attention, concentration, memory, speed of processing, judgment, and executive function (VA/DoD, 2009).

Post-Traumatic Stress Disorder and Blast TBI.

Our veterans typically suffer from comorbid disorders such as Post-Traumatic Stress Disorder (PTSD). Some of the symptoms of PTSD and bTBI overlap. Therefore, it is necessary to understand the differences between other closely related co-existing disorders, such as Post-Traumatic Stress Disorder (PTSD).

PTSD is an anxiety disorder caused by a psychological traumatic event. Symptoms may consist of avoidance behaviors, physiological hyperarousal and re-experiencing symptoms (VA Health Services Research & Development Service, 2009). Anyone can suffer from a traumatic episode that may cause PTSD, but military personnel are at a higher risk level. Vietnam veterans are estimated to have a 19% prevalence of developing PTSD (VA Health Services Research & Development Service, 2009). OIF soldiers' studies demonstrated a 17-25% prevalence of PTSD (Milliken, Auchterlonie, & Hoge, 2007). Studies have examined the co-occurrence of PTSD and bTBI.

Symptomatology of PTSD and bTBI are similar. With the lack of neuroimaging data for proof of bTBI, symptomatology becomes an important tool for diagnosis. In addition, it is not surprising to expect that veterans suffering from bTBI would also suffer from PTSD. Hoge, et al. (2008) reported 44% of returning U.S. soldiers form Iraq war that had bTBI met the criteria for PTSD. Some of the symptoms for PTSD are shame, guilt, re-experiencing symptoms. Symptoms for bTBI are headache, sensitivity to light and sound, memory deficits, vertigo, hearing loss, and executive function deficits. Overlapping symptoms of both disorders are depression/anxiety, insomnia, irritability/anger, trouble concentrating, fatigue, hyperarousal, and avoidance (Stein & McAllister, 2009). Stein and McAllister state that mTBI's reduced cognitive abilities such as problem-solving and emotional regulation may increase the risk for PTSD. The importance of this co-existence of disorders is that they may influence therapeutic responses. Intervention may need to be altered when a veteran has duel diagnoses.

Though literature has focused predominately on the rehabilitation of these cognitive issues (Cornis-Pop, et al., 2012; Roth, 2012; Vanderploeg, et al., 2008; Helmick, et al., 2010), rehabilitation is not part of the scope of this paper. Language deficits within the bTBI population is one of the goals of this paper. However, language concerns have had less attention in the literature. One of the problems with assessing language deficits in mTBI subjects is the weakness of standardized tests for subjects with cognitive-communication disorders. Many assessments currently utilized by speech-language pathologists lack construct validity, and are not normed on the TBI population (Turkstra, Coelho, & Ylvisaker 2005). However, the following studies examined language concerns in the mTBI population. Does this research generalize to the blast injured TBI population? Can the cognitive-communication deficits noted in the mTBI population be used to identify mTBI in the blast injured population?

Theoretical Framework

Extended language is defined as the combination of cognitive processes and higher-level language comprehension (Fitch, 2010). These cognitive processes include inferencing, Theory-of-Mind, executive functions and working memory. Inferencing requires the integration of one's background knowledge and the current text to draw information. Theory-of-mind refers to one's ability to understand or acknowledge others points of view, perspectives, motives, emotions, thoughts and/or beliefs about the world. Higher-level language comprehension refers to the comprehension of connected text, or pragmatic interpretations including figurative language (metaphors, idioms, similes), and inferencing (Fersti, Neumann, Bogler, & von Cramon, 2008). Extended language is beyond the comprehension of words and sentences. There are several models that address the complexity of extended language comprehension, the extended language network (Fersti et al. 2008), faculty of language in a broad sense (Fitch et al., 2005), and information processing theory of Massaro (1975).

Fersti et al. (2008) refers to an extended language network, which is involved in the comprehension of language. Fersti et al. explains how language comprehension requires more than just comprehension of words and sentences, but also cognitive processes such as theory of mind, attention, inferences, and self-monitoring to be sure that comprehension matches the communicative situation. All these processes require numerous brain regions to be activated thus resulting in what Fersti et al. refer to as "an extended language network (ELN). These authors demonstrated their model by completing a meta-analysis of neuroimaging studies on text comprehension. They examined twenty-three neuroimaging studies. They looked at four areas, resting baseline with test comprehension, non-language baseline (speech played backwards), coherent vs. incoherent language, and comprehension of metaphors. Results revealed an overlap for three of the four areas in the anterior temporal lobe, bilaterally. Each area also showed additional brain activation including the posterior cingulated cortex for coherence of text and other areas of the fronto-temporal regions. Thus, numerous areas of the brain are required for language comprehension, as other studies have also demonstrated since the publication of this meta-analysis (Oblese & Kotz, 2010).

The information processing theory of Massaro (1975) is a connectionist model that suggests that comprehension relies on the extraction of information at different stages of processing, which requires interpretation of both sensory and cognitive information simultaneously and sequentially. Comprehension occurs at both the peripheral and the cortical levels. Peripheral or sensory information includes auditory, visual and tactile data, and high-level cognitive skills include attention, speed of processing and memory.

Fitch's (2005) *faculty of language in a narrow sense* consists of all the mechanisms that partake in language acquisition as use. These mechanisms include cognitive processes, such as memory, theory of mind, and inferencing, plus audition, vision, sequencing, speech perception and vocal production.

Framework and Language Deficits Connections

The common factor in these models is that language requires multiple domains. How this applies to the TBI subject is that this population suffer from diffuse axon injuries that affect numerous parts of the brain. These injuries combined could affect the functioning of successful language from numerous sources, such as poor attention, memory, auditory or visual, or theory of mind. For example if an individual has decreased hearing then that individual may have increased difficulty with speech discrimination which in turn will affect their ability to interpret correctly a spoken message. The tone or inflection in a speaker's voice may also be missed, which also may interfere with the listener's ability to correctly comprehend a spoken message (Bellis, 2003). Auditory processing deficits will also interfere with a listener's ability to process auditory messages especially in the presence of background noise, or if the verbal message is lengthy, then part of the message is lost. Visual deficits may have a similar impact on comprehension.

Visual deficits may affect a person's ability to correctly interpret body language, facial expressions, and visual cues that assist in interpreting certain phonemes. If a subject has a duel sensory impairment, both visual and auditory impairments, then they are at a higher risk to have difficulty with comprehension of oral language. Cognitive deficits may also interfere with language comprehension.

Cognitive skills such as attention, memory, theory of mind, and speed of processing, are all important for successful language functions. There are several different forms of attention; selective attention and divided attention. Selective attention is best explained as the "cocktail party attention". This is when one is able to hold or stay focused upon a conversation while there are other conversations occurring around them at the same time. Divided attention refers to one's ability to focus upon two or more tasks simultaneously. This is also referred to as multi-tasking. Interference with one's sustained attention during instructions or a conversation will interfere with comprehension. The interruption of attention may result in missed information, or an inflection change, which changes the meaning of the message, therefore impeding comprehension (Cornis-Pop et al. 2012, Kristensen, Wang, Petersson, & Hagoort, 2013).

Discourse is conversational language, which includes more than just semantics and syntax. Discourse also includes inferencing, decoding of prosodic signals, and activation of memories. Prosodic stress facilitates inferencing by highlighting important information in a sentence (Wilson & Wharton, 2006). Stress also facilitates comprehension when a listener has decreased language processing (Cohen & Faulkner, 1986). In addition, stress can facilitate comprehension when a listener has decreased working memory capacity (Cevasco & Ramos, 2012).

Speed of processing is another cognitive process needed for comprehension. Speed of processing refers to the rate of speed one is able to interpret information and respond. Deficits in this area may result in difficulty with maintaining a topic during discourse, reduce one's response time to questions, or limit one's ability to accurately comprehend rapid speech (Cornis-Pop et al. 2012).

Theory of Mind deficits may affect language comprehension because it will interfere with one's ability to integrate the current text with one's ability to see or understand other's points of views, feeling, or intent. This is especially important for inferencing. Finally, memory has an important role in language skills. Comprehension and discourse both rely on memory capacity and recall. Memory includes many parts, such as semantic memory, episodic memory, procedural memory, and working memory. Limitations in memory abilities may interfere with language comprehension, inferences, ambiguities, and indirect requests, learning of new information, and one's ability to retain complex directions (Cornis-Pop, 2012; Moser, Fridriksson, & Healy, 2007; Gaudreau, Monetta, Macir, Laforce, Poulin, & Hudon, 2013; Wong, Murdoch, & Whelan, 2010). Working memory, for example has limited capacity element (Baddeley, 2003). This limited capacity explains how auditory information may be lost. If an individual has a reduced amount of capacity in their memory then this individual would need to use more energy to process information. This switch in energy would interfere with this individual's ability to retain all information heard leading to lost information, which would then impair comprehension of the verbal message. Therefore, a running conversation, or retention of complex directions could be impaired.

Figure 1. Conceptual framework diagram \

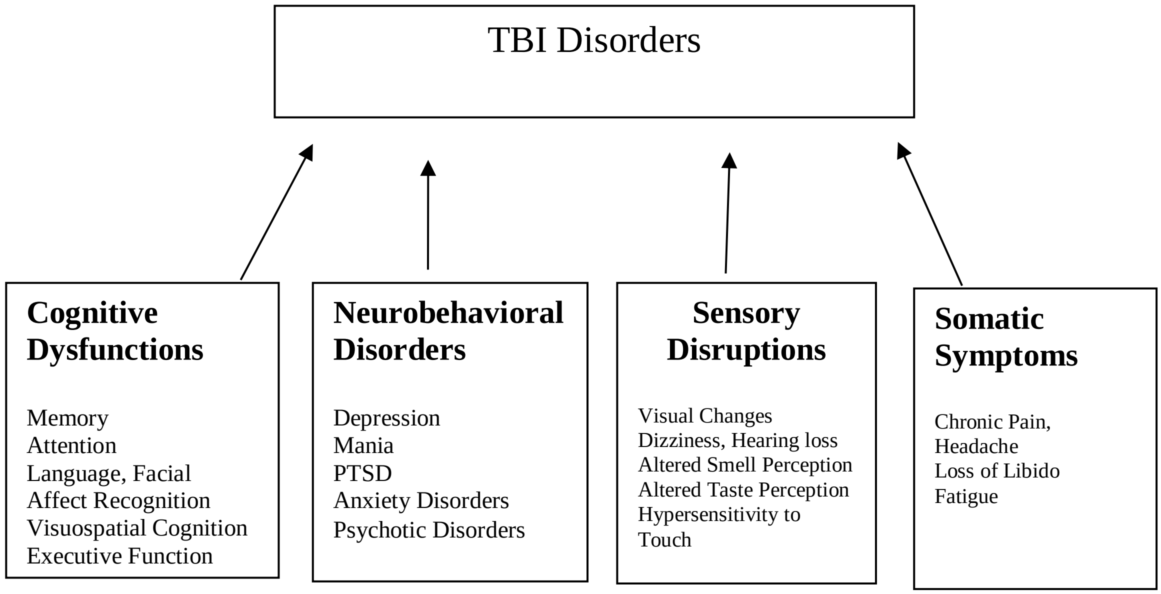


Figure 1. Clusters of neuropsychiatric symptoms of traumatic brain injury, (VA/DoD, 2009).

Chapter II

Literature Review

There are many cognitive and sensory abilities that can negatively impact language skills. Attention, working memory, central auditory processing, hearing loss and vision may individually impair language skills. Each one of the above have been identified as deficits with blast induced traumatic brain injured (bTBI) service members. Blast TBI is the main injury with our service members during the war on terror occurring in Iraq and Afghanistan. There is limited research on language deficits in this population, but the literature demonstrates deficits in attention, working memory, auditory processing, executive function, (Belanger, 2009; Hicks, 2010; Kennedy, 2010), and dual sensory impairments, which included hearing and vision loss (Gallun, Lewis et al. 2012, Saunder & Echt, 2012). A parallel could be drawn to suggest language deficits may be present in this population secondary to the presents of cognitive and sensory deficits.

Blast TBI is defined by the Department of Defense as: Loss of consciousness 0-30 minutes; Alteration of consciousness/mental state - a moment up to 24 hours; Post-traumatic amnesia – 0-1 day; Glasgow Coma Scale (best available score in first 24 hours) – 13 to 15 (after 30 minutes).

This is the same definition for mild TBI. There are four types of blast injuries - primary blast injury, physical penetration, tertiary blast injury, and quaternary blast injury.

Primary blast injury is the result of rapid changes in atmospheric pressure that is created by a blast wave. Bodily organs and tissues have different density levels and therefore are accelerated at different relative rates. This results in displacement, stretching and shearing forces (Taber, Warden & Hurley, 2006). Air filled cavities, such as the lungs or middle ear, are most susceptible to damage (Snell & Halter, 2010). Physical penetration injuries refer to explosive device fragments, or other object projectiles caused by the blast that enter the head. Tertiary blast injury refers to the injury as a result of being thrown, pushed or shoved into another object. Finally, injuries from burns, radiation, or inhalation of hot explosive gases are quaternary blast injuries (Snell & Halter).

Approximately 1.7 million soldiers from two theaters have been deployed during the war on terror. They are Operation Iraqi Freedom (OIF). 2001-December 2011, and Operation Enduring Freedom (OEF), Afghanistan. Fifteen to nineteen percent of these soldiers have returned with blast related injuries. This accounts for around (Hoge, et al., 2008) 255,000 – 323,000 soldiers. The DoD (2009) - estimated that 20%, or 300,000 OEF/OIF soldiers have sustained a TBI during deployment, which mostly consist of mTBI's. There are significantly more injuries from explosions than from gunshots.

Blast TBI Diagnosis Criteria.

The Department of Defense's (2009) criteria for a mTBI is as follows: Loss of consciousness 0-30 minutes; Alteration of consciousness/mental state - a moment up to 24 hours; Post-traumatic amnesia – 0-1 day' Glasgow Coma Scale (best available score in first 24 hours) – 13-15. It is estimated that 20%, or 300,000 OEF/OIF soldiers have sustained a TBI during deployment, which mostly consist of mTBI's (Department of Veterans Affairs Health Services Research & Development Service, 2009). Drake et at. (2010) screened 7909 marines between the years of 2004 and 2006 for positive occurrence of traumatic brain injury. Of these marines 23% (n = 1799) reported sustaining a physical injury. Of the 1799, 27.9% were reported to be secondary to a blast injury (n = 395). The Armed Forces Health Surveillance Center reported approximately 135,000 military service members were diagnosed with TBI between January of 2003 and January of 2010 (Graner, Oakes, French & Riedy, 2013). How is a bTBI identified?

Initially, there was some argument over whether these soldiers truly present with brain injuries, or where their symptoms are side effects from post-traumatic stress disorder. mTBI's are known to not show alteration in brain structure with CT, or with traditional MRI's (Graner, Oakes, French & Riedy, 2013). A research study by Peskind, et al. (2011) used PET imaging to examine 12 Iraq War veterans with mTBI from repetitive blast-trauma with and without PTSD. Their findings found that there was a decrease in cerebral maetabolic rate of glucose in the cerebellum, vermis, pons and medial temporal lobe. These findings suggested that PTSD was not a factor in the symptoms associated with bTBI. Diffusion tensor imaging (DTI) is a more advanced form of MRI that is more sensitive to axonal injuries as it looks at subcortical white matter. Will DTI reveal brain damage in bTBI subjects?

Mac Donald, et al. (2011) used DTI to scan 63 US soldiers with a diagnosis of bTBI within 90 days post injury. These soldiers had been exposed to a primary blast injury, plus a second category of blast injury, such as trajectory. Twenty-one soldiers with no diagnosis of bTBI, but were exposed to a primary blast, served as controls. Results revealed abnormalities in the middle cerebellar peduncles ($p<0.001$), cingulum bundles ($p=0.002$), and right orobitofrontal white matter ($p=0.007$). Animal studies (swine, monkeys, and rats) all revealed neuronal changes in the white matter after exposure to blast waves (Bauman, 2009; Lu, 2012; Vandevord, 2012). The Purkinje neurons in the cerebellum and pyramidal neurons in the hippocampus were noted to be the most vulnerable to blast overpressure in monkeys (Lu, et al., 2012). A more recent study of post-mortem autopsies revealed distinct differences between soldiers with blast exposure and a control group of brains. Shively et al. (2016) examined five brain specimens of soldiers who had died shortly after a severe blast exposure. They compared these brains with non-military brains with no history of blast exposure but had either chronic impact TBI or chronic exposure to opiates.

All five of the blast exposed brains revealed astroglial scarring in the subpial glial plate, grey/white matter junctions and structures lining the ventricles as well as penetrating cortical blood vessels. This specific pattern of scarring may be unique to chronic blast exposure and it lines up with the general principles of blast biophysics. Post-concussion syndrome is more robust in explaining the neurological damages from repeated mTBI's.

The most common cause of a Post Concussive Syndrome (PCS) is repeated concussions occurred during a contact sport activity such as soccer or boxing. The anatomical structure called the Fornix is susceptible to damage from a concussion. The Fornix is half-way under the Corupus Collosum. The Fornix is a white matter structure that is important for output from the hippocampus. The Fornix is connected with the mamillary body and septum, but is loosely connected to the septum pellucilum. The anatomical position and loose connections is what portrays this structure as "a delicate" structure (Bigler, 2008).

Are there common neurological structures affected by a concussion? Bayly, et al. (2005) was addressing this question in his study. Bayly, et al. studied MRI's of subjects who the authors subjected to a head fall of 2 cm. MRI's where taken before and immediately after the drop. The authors stated that this movement was approximately 10-15% of the acceleration required for a soccer player who was "heading a ball".

The authors recorded the following effects upon the brain. The brain rotated backward and upward around the base of the brain. This is connected by the dural rings. Structures such as the distal internal carotid arteries, the optic and oculomotor nerves, olfactory tracts and other structures pass through the dural rings. The anterior portion of the brain is compressed and the posterior portion of the brain is stretched. The compression of the superior-frontal surface is against the top of the cranial vault. The brain elongated as the inertia pulls the brain backward and clockwise. Now the brainstem structures shortened and experienced shearing, while the posterior and inferior parts of the brain continued to rotate downward and forward.

Another research team, Viano, et al. (2005), also wanted to exam the cranial structures of the brain affected by a concussion. They examined NFL football players who had experienced a concussion on the field. The authors did this by simulating the cranial movement of the impact that was identified on video tapes of the incidents. What the authors found was that the initial impact occurred in the temporal lobe adjacent to the impact. Most of the shearing had occurred in the fornix, midbrain and corpus callosum. They also reported 4-5 mm displacement of the hippocampus, caudate, amygdale, anterior commissure, and midbrain. It is important to note that the medial temporal lobe and midbrain are close in proximity to each other.

Zhang, Heier, Zimmerman, Jordan, and Ulug (2006) used diffusion tensor imaging, a more sensitive MRI technique, to examine 32 professional boxers.

All of the boxers demonstrated some white matter abnormalities, and seven of these boxers demonstrated significant white matter abnormalities. Most of the abnormalities were at the level of the corpus callosum, which correlates with Viano et al. (2005) study. This also is consistent with a study completed by Chappell, et al. (2006). Chappell, et al. (2006) studied 81 professional boxers using DTI methods and found abnormalities in the white matter. Omalu, et al. (2005) and Bigler, (2004) both compared autopsies of brains that had sustained concussions with their MRI's. Both studies found hemorrhagic lesions.

PET scans are another method to assess brain function, but symptoms may not always be exposed due to different task demands on each subject. For example, Chen, Kareken, Fastenau, Trexler, and Hutchins (2003) examined five subjects who had sustained a concussion. Four of these subjects presented with PPCS neurobehavioral symptoms but no abnormalities were revealed in a PET scan until the subjects were asked to perform a spatial working memory task. When asked to perform this task prefrontal cortex abnormalities were observed. Bernstein (2002) used evoked responses with subjects who had a history of concussions but no neurobehavioral symptoms. When these subjects were presented with a multi-task that required both auditory and visual discrimination skills they performed significantly different from the control group. Umile, Sandel, Alavi, Terry, and Plotkin (2002) used PET scans and neurocognitive testing to demonstrate that mTBI subjects demonstrate temporal lobe damage and memory deficits. These studies demonstrate that the abnormalities these subjects present with may be skill specific.

Assessing brain damage can also be obtained by assessing biochemical changes in the neurotransmitter disruption. Zetterberg, et al. (2006) studied cerebrospinal fluid in 14 armature boxers 7-10 days and 3 months post a boxing match and compared to a group of controls that had no physical contact events. The findings revealed neuronal injury byproducts in the cerebrospinal fluid correlated with the number of hits to the head during a fight without knock outs. Ost, et al. (2006) correlated a microtubular binding protein, tau, found in cerebral spinal fluid with the severity of TBI, so therefore this protein could be used as a marker of white mater injury.

MRI's, DTI's, PET scans and biochemical changes are all methods used to examine neurological changes from concussions. Another way to predict if a subject will suffer from post-concussion symptoms is by the examination of the peri-vascular spaces. Mild TBI's have demonstrated dilated peri-vascular space changes, white matter volume changes, and chemical composition changes (de la Plata, et al. (2007). Konsman, Drukarch, & Van Dam (2007) also reported peri-vasular inflammation and hemosiderin deposits in the peri-vascular to be markers of white matter injury.

How do these abnormalities correlate with neurobehavioral symptoms? Bigler (2008) reported how anatomical changes that occur from the rotational force that occurs from compression that is correlated with concussion symptoms. Bigler (2008) stated that slight changes in the upper brainstem and reticular activating system will affect consciousness. Mechanical compression of the perirhinal and entorhinal cortices will affect input and or output to the hippocampus through the fornix and the connection with the anterior thalamus and cingulated. The medial temporal lobe and basal forebrain is associated with emotional regulation. Stretching of the internal carotid artery is associated with posttraumatic migraines. Finally, the symptom of fatigue is associated with hormonal changes from the disruption of hypothalamic-pituitary area. Speed of processing is slowed after a concussion. This is correlated to the compromise of the integrity of white matter pathways. Long-coursing axons are more vulnerable for inter-hemispheric connections (Cecil, et al. 1998), such as the corpus callosum and anterior commissure.

Autopsy studies found axonal injury in the fornix (Blumbergs, 1994; Viano, 2005). The fornix is a white matter structure that contains projecting axons from the hippocampus. The hippocampus is important for memory. Therefore, disruption in the fronix integrity may cause the disruption in short term memory (Bigler, 2008).

Why is there inconsistency in the research data? First, everyone has different thresholds for how many concussion occurrences needed before lasting deficits are exhibited (Zhu, Prange, & Margulies, 2006), and no two subjects are the same. In addition, poor research designs such as small sample numbers, samples of convenience and litigation bias, which confounds research, are all research limitations. Large subject groups can also affect research results in that individual subject symptoms can be washed out of the total group results. In addition, many of the studies fail to control for hearing loss, which may affect test results. Finally, lack of cohesiveness with terminology, and operational definitions can affect the consistency of research data.

In summary the vulnerability of the upper brainstem, hypothalamic-pituitary axis, medial temporal lobe, basal forebrain, long-coursing white matter fibers (corpus collosum and fornix) are anatomical regions of the brain associated with post concussive symptoms. Still most military personnel are diagnosed through neurocognitive assessments rather than imaging.

Functional Diagnostic Criteria of Blast TBI.

Most studies for bTBI look at neurocognitive symptoms. Some of the symptoms reported are memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012). The Veterans Affairs/Department of Defense (2009) list the following neurocognitive areas this population may exhibit deficits in: attention, concentration, memory, speed of processing, judgment, and executive function. Executive function includes problem solving, planning, organization, and mental flexibility (French & Parkinson, 2008). Is there similarities in the bTBI and mTBI cognitive impairments?

Luethcke, Bryan, Morrow, and Isler (2011) compared cognitive and psychological symptoms between bTBI and non-blast mTBI subjects. They found very little differences between the two groups in the first 72 hours after injuries. The nonblast group lost consciousness more frequently, had a longer duration of unconsciousness and initially experienced more balance problems, nausea, and vomiting. No differences were found between the two groups in regards to psychological symptoms. Cognitive performance revealed no differences in the subject's speed of response or accuracy. No other between differences could be calculated due to limited sample size. The author's suggestion was to repeat this study with a larger sample size. Since research is lacking with military subjects we can turn to the concussion literature, which is the closest in similar symptoms and findings.

Sports literature has addressed the effects of multiple and single concussions on cognitive areas. A meta-analysis completed by Belanger, Speigel, and Vanderploeg (2009) examined the literature on this subject from 1970 through 2009. Out of 123 studies, only eight met their criteria. The authors were specifically interested in the effect sizes by cognitive domain and overall cognitive function. There results revealed the overall effect size on neuropsychological performance was 0.06 and for specific cognitive domains it was found that only executive functions and delayed memory had statistical significance with effective sizes of d=0.24; d=0.16, respectfully. These are small to medium in size. These studies reported an average of two to three concussions per subject. Our veterans are typically exposed to more occurrences of blasts than two or three.

In summary, the literature identifies common neurocognitive symptoms in both the blast mTBI group and the non-blast mTBI group. These symptoms consist of memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012), and deficits in attention, concentration, memory, speed of processing, judgment, and executive function (VA/DoD, 2009).

Post-Traumatic Stress Disorder and Blast TBI.

Our veterans typically suffer from comorbid disorders such as Post-Traumatic Stress Disorder (PTSD). Some of the symptoms of PTSD and bTBI overlap. Therefore, it is necessary to understand the differences between other closely related co-existing disorders, such as Post-Traumatic Stress Disorder (PTSD).

PTSD is an anxiety disorder caused by a psychological traumatic event. Symptoms may consist of avoidance behaviors, physiological hyper-arousal and re-experiencing symptoms (VA Health Services Research &

Development Service, 2009). Anyone can suffer from a traumatic episode that may cause PTSD, but military personnel are at a higher risk level. Vietnam veterans are estimated to have a 19% prevalence of developing PTSD (VA Health Services Research & Development Service, 2009). OIF soldiers' studies demonstrated a 17-25% prevalence of PTSD (Milliken, Auchterlonie, & Hoge, 2007). Studies have examined the co-occurrence of PTSD and bTBI.

Symptomatology of PTSD and bTBI are similar. With the lack of neuroimaging data for proof of bTBI, symptomatology becomes an important tool for diagnosis. In addition, it is not surprising to expect that veterans suffering from bTBI would also suffer from PTSD. Hoge, et al. (2008) reported 44% of returning U.S. soldiers form Iraq war that had bTBI met the criteria for PTSD. Some of the symptoms for PTSD are shame, guilt, re-experiencing symptoms. Symptoms for bTBI are headache, sensitivity to light and sound, memory deficits, vertigo, hearing loss, and executive function deficits. Overlapping symptoms of both disorders are depression/anxiety, insomnia, irritability/anger, trouble concentrating, fatigue, hyper-arousal, and avoidance (Stein & McAllister, 2009). Stein and McAllister state that mTBI's reduced cognitive abilities such as problem-solving and emotional regulation may increase the risk for PTSD. The importance of this co-existence of disorders is that they may influence therapeutic responses. Intervention may need to be altered when a veteran has duel diagnoses. The overlap of symptoms also may influence proper diagnostic of the bTBI, as they may be diagnosed with only PTSD.

Upper and Lower Neuron Symptoms in bTBI

The literature does identifies common neurocognitive symptoms in both the blast mTBI group and the non-blast mTBI group. These symptoms consist of memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012), and deficits in attention, concentration, memory, speed of processing, judgment, and executive function (VA/DoD, 2009).

These service members demonstrate deficits in working memory. Working memory and language are correlated. Research demonstrates that decreased working memory capacity decreased a subject's comprehension of complex sentences (Baddeley, 2003, Moser, Fridriksson, & Healy, 2007). Attention and language are correlated. Poor attention or decreased ability to divide attention limits ability to learn new information, follow directions, and follow conversation in social situations (Baddeley, 2003, Kristensen, Petersson, & Hagoort, 2013). Auditory attention and sentence comprehension activate same brain networks suggesting both are interactive. Auditory processing and language are connected. Research by Tun, Williams, Small, & Hafter (2012) reveal that auditory processing is needed for language comprehension. Dual Sensory Impairment-vision and hearing are connected (Lew, Pogada, Baker, et al., 2011, Lew, Garvert, Pogoda, et al., 2009). Facial expressions, gestures and other nonverbal cues may be missed with visual perceptual impairment and hearing loss would create difficulty with interpreting the tone of a person's voice. Tone facilitates a person's ability to interpret a speaker's mood or intent. So the questions arise that if bTBI subjects have weaknesses with attention, working memory, auditory processing might they have related language deficits in higher level language areas such as comprehension of inferencing, and ambiguity?

Auditory Processing Deficits

In addition to peripheral hearing damage there may be central auditory system damage. Central auditory processing is the auditory system mechanisms and processes responsible for sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal resolution, temporal masking, temporal integration, temporal ordering, and auditory performance with competing acoustic signals and degraded acoustic signals (ASHA, 1996). Shearing and stretching forces from blast exposure can cause damage to the brainstem, temporal lobe (Fausti, et al. 2009) and corpus callosum (Taber, Warden, & Hurley, 2006). Finally, damage to the central nervous system may cause vestibular impairment. Since the integrity of the ear is susceptible to damage from a blast, what does the literature report for the frequency of peripheral and central auditory deficits in our military personnel?

Walter Reed Army Medical Center reported 64% of the blast injured veterans have hearing loss (Chandler, 2006). Roth (2012) reported 49% of the bTBI soldiers seen in her clinic presented with audiological symptoms. Of the 49% that presented with audiological symptoms, 80% spontaneously recovered within 6 months of diagnosis. The remaining 20% would have tympanic membrane and/or ossicles surgery. Lew, et al. (2011) found in their study that vets with bTBI have a higher incidences of auditory impairments. In addition to peripheral hearing loss and auditory processing deficits there are other audiological findings.

Hoffer, et al. (2010) reported that blast exposure caused vestibular disorders, such as vertigo, and dizziness, and these symptoms were significantly different than those subjects with blunt head trauma. Blast TBI have exercise-induced dizziness soon after the onset of exercise, whereas the blunt trauma patient have dizziness when finished with exercising. In addition, the bTBI group exhibited more significant headaches and disequilibrium that the blunt trauma group. Another finding was within the blast injured group. The subacute bTBI group, (4 – 30 days post exposure), present with only 1 out of 21 patients with central auditory processing abnormalities (<5%), whereas 11 of the 41 (27%) subjects from the chronic group, (more than 30 days post blast exposure), demonstrated with central auditory processing abnormalities. This suggests that the brain injury increases over time possibly due to global neurochemical and gene expression changes. What was similar between the subacute and chronic groups was the presence of a significant hearing loss (43% and 49% respectively). Other researchers have found similar findings.

Lew, Jerger, Guillory and Henry (2007) reviewed medical charts of 252 soldiers between 1999 and 2006 with the mean age of 33.5 years. The subjects were divided into two groups; one TBI group consisted of soldiers before the OIF conflict began (control group) and one TBI group consisted of soldiers after the OIF conflict began. The second TBI group was then divided into two additional groups, a non-blast related TBI group and a blast related TBI group. Some of the differences found were the prevalence of patient report of hearing loss (28% control group; 49% experimental group). This was a significant difference $p = 0.001$. Not all of the patients who complained of a hearing loss received a hearing examination, but of the subjects who did receive an audiological exam, the results are as follows: Non-blast TBI group ($n = 108$) 44% complained of hearing difficulty. Of that 44%, 4% had normal hearing the rest had a hearing loss (mostly pure sensorineural, 47%, 11% conductive, 8% mixed, 30% unclassified). In the bTBI group ($n = 42$) 62% complained of hearing difficulty. Of that 62%, 11% exhibited normal hearing with the remaining having a variety of hearing deficits (58% pure sensorineural, 8% conductive, 19% mixed, 4% unclassified). The authors speculate that the 4% and 11% of veterans that demonstrated normal peripheral hearing, but complained of hearing difficulties, may have central auditory pathway impairments. Of the five top audiological diagnoses reported among veterans, auditory processing disorders were ranked number five (Roth, 2012).

Gallun, Diedesch, et al. (2012) wanted to specifically examine the performance of bTBI on central auditory processing tests. These authors assessed 36 veterans one year post exposure to a blast. Seventeen of the subjects did not have a TBI, and nineteen of the subjects were diagnosed with a mTBI. A control group of 29 subjects had no history of blast exposure. The control group was matched by age and hearing acuity. Hearing loss was allowed up to 50 dB. The subjects underwent behavioral and electrophysiological testing. Three auditory processing tests, which demonstrated large effects for blast exposed subjects were: Gaps-In-Noise task, which looks at auditory temporal resolution, The Masking Level Difference task, which looks at binaural processing and sound localization, and the Staggered Spondaic Words test, which is a dichotic test. These tests are consistent with damage to the cortex and corpus callosum. Damage to the temporal lobe and corpus callosum is consistent with blast literature. A limitation to this study is the allowance of a hearing loss, which could bias the findings of APD. The authors attempted to control for the hearing loss by matching the hearing loss in the control group and the Staggered Spondaic Words test they used was supposed to be resistant to hearing loss.

Later research not only confirmed auditory concerns with this population but found that the auditory deficits were coupled with visual perceptual deficits. A new term was coined “dual sensory impairments” (DSI) (Lew, et al. 2009; Lew, et al. 2010; Lew, et al. 2011; Saunder & Echt, 2012). The implication that auditory comprehension may be impaired from DSI has value. Decreased vision along with decreased hearing can cause subtle problems, such as difficulty with interpreting the tone of a person’s voice. Tone facilitates a person’s ability to interpret a speaker’s mood or intent. Facial expressions, gestures and other nonverbal cues may be missed with visual perceptual impairment (Saunders & Echt). A combination of the two deficits compounds the chances for an individual to encounter comprehension difficulties. Are auditory deficits reported in the nonmilitary TBI population literature?

Bergemalm and Lyxell (2005) found 58 percent of the 22 TBI patients that they studied presented with central auditory processing disorders. Subjects with peripheral hearing were deleted from the study. Nolle, Todt, Seidl, and Ernst (2004) studied 31 subjects with normal hearing and report loss of stapedial reflex responses in blunt trauma and correlate this finding with diffuse axonal injury of the central auditory pathway. Bernstein (2002) examined 13 students with history of concussions and identified deficits with tonal discrimination. Musiek, Baran, and Shinn (2004) report on a single subject case. The subject was 13 months post trauma and complained of the following difficulties: understanding what people were saying to her, memory, fatigue, reading comprehension, math, organization, and dizziness. Audiological pure-tone and speech recognition tests were all within normal limits. Central auditory tests revealed abnormal findings for all tests except frequency patterns. So, research with military bTBI and nonmilitary mTBI both show evidence of central auditory processing deficits.

Deficits in auditory processing can present functionally as language comprehension deficits. Poor auditory processing will affect comprehension of voice onset time, blocking out background noise, localization of sounds, and speech discrimination (Bellis, 2003). However, bottom-up factors can be affected by top-down factors such as attention and memory (Bellis, 2003). How does attention and memory affect central auditory processing? Moreover, how does that relate to language disorders?

Attention, Working Memory, and Auditory Processing

Comprehension is not just based on the encoding of speech, which is the job of the central auditory process; it is also reliant to higher-order cognitive functions of attention and memory. For example, an attention deficit would interfere with a stimulus being perceived by a person. Therefore, the information could not be encoded or stored in the memory system (Bellis, 2006), and even if the auditory processing system was intact comprehension of the signal would not occur.

Attention is in charge of processing the information that is most important to the current moment. There is more information available in the environment than a person can interpret at a given moment. Selective attention filters the information and allows us to focus on the pertinent data needed for the moment. Therefore, attention is necessary for central auditory processing to function properly. What is the role of working memory for comprehension?

Working memory has an important role for comprehension. Working memory capacity has been linked to an individual's ability to inhibit processing of irrelevant information (Macken, Phelps, & Jones, 2009). So, indirectly working memory could negatively impact the processing of auditory information. The literature is rich in data that supports a correlation between attention, working memory, and CAP.

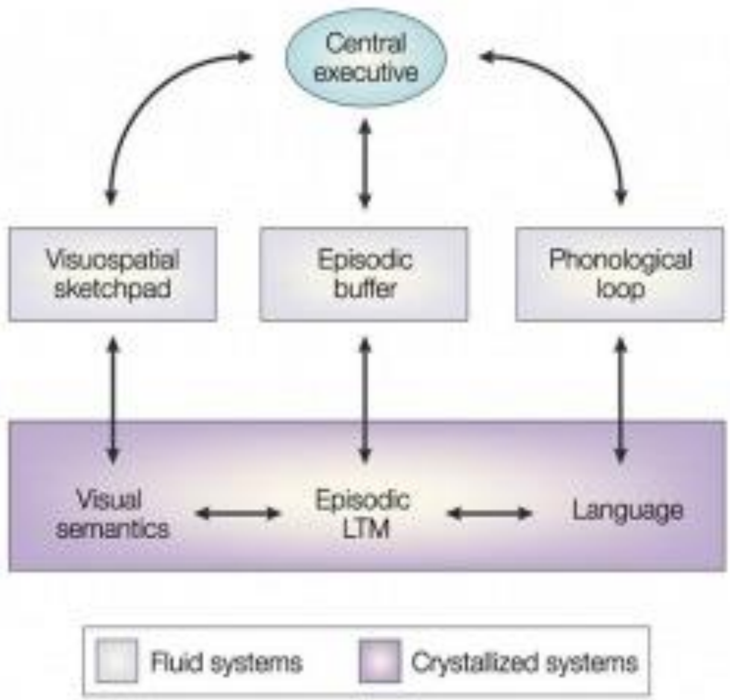
A literature review completed by Moore (2011) reported evidence that supports that attention and memory is the bases for listening problems in children. Moore also stated that his research resulted in similar findings with adults. Lum & Zarafa (2010) reported significant correlation between verbal working memory and auditory processing. The authors used a group of 16 specific language impaired children and a control group matched by age and intelligence with no hearing or visual deficits. The authors found a small effect size was observed on the Competing Words and Competing Sentences subtests, and a medium effect size was observed on the Filtered Words and Auditory Figure-Ground subtests. They found this pattern similar to previous studies that found dichotic listening tasks placed higher demands on verbal working memory than filtered words or auditory figure-ground tasks. Iliadou & Bamiou (2012) also found correlations between working memory, attention and CAP tests. These authors examined 38 children with a diagnosis of auditory processing deficits and 20 age and gender matched controls. These authors found a strong correlation between duration processing tests and memory and attention. They hypothesized, that these findings may be due to either temporal processing efficiency needed for speech in noise perception, or it may be that the duration processing task requires the use of short-term auditory memory, or poor ability to switch attention. Dichotic digits task was moderately correlated with memory and attention. Dichotic listening requires interaction by the corpus callosum for bottom-up and top-down processes. Though the above studies focused on children, the literature also confirms a connection with working memory, attention, CAP, and auditory comprehension in adults.

Tun, Williams, Small, & Hafter, (2012) completed a literature review on the effects of aging on auditory processing and cognition. These authors report how speech places a significant weight on attention and working memory, because in real time words are spoken at a rapid rate of 120 to 180 words per minute. This places tremendous stress on attention and memory because the listener cannot go back to re-play the speakers words, the listener must attend to the speech signals so as to encode the auditory signals, access lexical items, syntax, and semantic operations, all while holding onto previous information in the memory system. The authors report that the literature presents data to support how the cognitive functions of divided attention, and selective attention, and switching attention all decline in the aging population. These declines are correlated to a subjects increased difficulty with listening with background noise, which then may lead to the elderly population’s decline in quality of life activities, such as giving up social activities that require this skill.

Attention, Working Memory, and Language Deficits

As previously stated attention and working memory are heavily relied on for language comprehension, because in real time words are spoken at a rapid rate of 120 to 180 words per minute. An individual needs to process and encode the auditory signals, lexical items, syntax, and semantics, while they store in their working memory previously stated information. This is all needed in order to carry on a conversation. Baddeley (2003) reports how memory and attention are needed to comprehend complex sentence structures. Comprehension depends upon the ability to retain the beginning of a sentence to accurately interpret the whole meaning. The limited capacity theory of working memory states that the phonological loop or verbal working memory, which is made up of storage and processing function, share the same limited amount of cognitive resources. The processing portion is responsible for the language operations, such as lexical, morphological, grammatical, and/or propositional functions. The storage portion is responsible for temporarily retaining verbal information that has been processed. If the processing portion is weak, then the individual may need to give more energy to processing difficult information and then they may forget some of the information they heard. If the storage portion is limited then they will use more energy to store the data and have less to process new information (Hay & Moran, 2005). Does the literature identify attention and memory deficits in the bTBI population?

Figure 2. Baddeley's Working Memory Model (2003)



There are numerous studies that examine the neurocognitive symptoms in bTBI subjects. Some of the symptoms reported are memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, 2010), speed of processing and executive functions (Cornis-Pop et al., 2012). The Veterans Affairs/Department of Defense (2009, 2016) reports the following neurocognitive deficits that bTBI population may exhibit: attention, concentration, and memory, speed of processing, judgment, and executive function. Executive function includes problem solving, planning, organization, and mental flexibility (French & Parkinson, 2008). Therefore, since the literate demonstrates that the bTBI have working memory, attention and auditory processing deficits, then we would expect bTBI to demonstrate language deficits.

Working Memory and Traumatic Brain Injury

Traumatic brain injured subjects are susceptible to axon sheering especially of the frontal lobe (Mandalis, Kinsella, et al. 2007). We know that the frontal lobe is important for the episodic buffer and central executive functions of working memory, (Purves, Brannon, et al. 2008), therefore it stands to reason that traumatic brain injured subjects would demonstrate some deficits with working memory. Pediatric brain trauma literature has found identical findings to the working memory literature in terms of language processing, decreased ability to learn new vocabulary, decreased recall on narratives, decreased sentence comprehension, and decreased ability to complete expository tasks.

Hay and Moran (2005) wanted to examine the relationship between working memory and discourse with school aged children (M = 12.0). They found high correlation with working memory and episodic structures, number of words used, number of T-units used and number of propositions used. They did not find a correlation with working memory and developing a moral to a story or production of complex sentences. Moran, Nippold, and Gillon (2006) wanted to examine further into this relationship of working memory and discourse by specifically examining proverb comprehension. They studied adolescent children that had had their head injury prior to age ten years and compared them to age matched peers. The traumatic brain injured (TBI) group scored significantly lower than their peers ($p < 0.01$), with a large effect sized ($d = 0.56$). Mandalis, Kinsella, Ong, and Anderson (2007) examined moderate to severe traumatic brain injured children (ages 6 -16). Their purpose was to investigate the association between working memory and new learning of vocabulary. The traumatic brain injured group when compared to a control group was less efficient at learning new verbal material and recalling information. The above studies addressed children, what about adult studies? Do adult TBI's demonstrate similar language processing deficits that are associated with working memory?

Adult research has identified three language processing skills that are correlated with working memory and TBI subjects. The first was narrative recall, the second was verbal learning, and the third was discourse. Kennedy and Nawrocki (2003), and Kennedy (2004) both tested on narrative recall and their ability to predict their accuracy. The earlier study examined 15 TBI adults in their mid-30. The later study examined 13 TBI subjects in their mid-30. Both studies matched the subjects with healthy controls matched for age, gender and years of education. Both studies found a significant difference between groups on recall of narrative information ($p = 0.02$; $p = 0.007$) respectively. However, the later study also looked at recall of noun pairs. On this task there was not a significant difference between the TBI and controls

(p = 0.73). The authors attributed this result to the method design in which the TBI subjects were allowed 9 seconds vs. the control group had only 3 seconds to study each noun pair.

Verbal learning differences in mTBI were examined by Geary, Kraus, Pliskin, and Little (2010). They were interested in subjects who reported chronic memory and attention difficulties, but these subjects' neuropsychological assessments did not verify their complaints. Their subjects were all employed in their 20's to 40's (M = 32.5 years). The authors ruled out depression, anxiety and apathy variables. Using the *California Verbal Learning Test -2*, the authors assessed the subjects' verbal learning. The subjects are given a list of words 5 times to recall. There findings demonstrated statistically significant difference between groups on the first learning trail, but not the remaining four trials. The authors applied this finding to functional situations. In conversation or in the work place mTBI subjects would only have the ability to hear information once. This is not sufficient due to their limited storage/processing ability. Research on this population's discourse ability would verify this hypothesized application.

Youse and Coelho (2005) examined discourse in TBI subjects. They recruited 45 moderate to severe TBI's ages 16-69. They theorized that deficits in working memory would reduce the efficiency and organization of language production in the TBI population. The subjects were required to retell a story and generate a story. Story retell placed demands on working memory processing and storage. All results for story retelling and story generation were significant with $p < 0.05$ with moderate effect sizes; $r = 0.36$; $r = 0.30$, respectively.

In summary, the limited capacity theory of working memory states that the phonological loop or verbal working memory, which is made up of storage and processing function, share the same limited amount of cognitive resources. The processing portion is responsible for the language operations, such as lexical, morphological, grammatical, and/or propositional functions. The storage portion is responsible for temporarily retaining verbal information that has been processed. If the processing portion is weak, then the individual may need to give more energy to processing difficult information and then they may forget some of the information they heard. If the storage portion is limited then they will use more energy to store the data and have less to process new information (Hay & Moran, 2005). This theory has been supported in the literature presented in this paper. Subjects with mild traumatic brain injury presented with language processing deficits in learning new vocabulary, decreased ability for story recall (narratives), decreased ability for expository tasks, and decreased proverb comprehension. These language skills are important for conversational discourse. It would then be theorized that mild traumatic brain injured subjects would be confronted with difficulty when engaged in conversational speech.

There are several limitation to these studies. Some studies had small numbers of subjects (Moran, et al. (2006), Kennedy & Nawrocki (2003), Kennedy (2004), Salis (2011), Hay & Moran (2005), and Gilcrest, et al. (2008). Many did not discuss the power needed to insure robust findings. Several studies only used female subjects, (Smith, 2011 and Moser, Fridriksson & Healy 2007), reducing their generalizability. However, the number of different studies with similar findings increases the strength of these study's findings.

Language Deficits and Mild TBI/Blast TBI.

Current literature on language deficits with bTBI is limited. Parrish, Roth, Roberts and Davie (2009) completed a retrospective study on 117 subjects from the San Diego Naval Hospital to explore methods, or instruments that would confirm communication concerns described by service members returning with bTBI. They used portions of the Woodcock-Johnson III, Attention Process Training Test, the Functional Assessment of Verbal Reasoning and Executive Strategies (FAVRES), and the Speech Language Cognitive Rating Scale (SLCRS). The latter is a questionnaire with a four-point Letcher rating scale. On the SLCRS the patients reported word finding and recalling of names most concerning. The WJ-III found these subjects to score below one standard deviation on subtests and clusters that measured cognitive efficiency, visual matching, and retrieval fluency. A few patients had difficulty with auditory working memory and verbal tasks. The APT identified difficulty on selective and divided attention subtests. Finally, the FAVRES identified slow speed of information processing. A limitation to this study is that the authors did not state if they controlled for hearing loss. Hearing loss is common with blast injured veterans, and can affect test results.

Luethcke, Bryan, Morrow, and Isler (2011) reported very little difference in neurocognitive deficits between bTBI and non-blast mTBI, therefore can we make the argument that the language differences would not vary between these two groups as well?

Whelan and Murdoch (2006) investigated the impact of mTBI on language function in the non-military population with five subjects. They used the following assessment tools – the Neurosensory Comprehensive Examination for Aphasia, Boston Naming Test, Test of Language Competence, The Word Test-revised, Wiig-Semel Test of Linguistic Concepts. Though they did not find statistical significance between groups, they did find some trends. The trends demonstrated weaknesses on tasks that would require cognitive flexibility such as comprehension of complex language (i.e. inferences, interpreting figurative language, and ambiguity). In 2013 Barwood and Murdoch assessed 16 mTBI subjects with several language assessment tools including *the Word Test – revised* and the *Test of Language Competence – Expanded*. Results revealed significant, $p = 0.01$ or less for associations, synonyms, ambiguous sentences, figurative language, and inferences.

Several other studies have also examined language deficits in mTBI (King, 2006a; King, 2006b; Wong, 2010). These studies found word finding deficits in mTBI in civilian subjects. King, Hough, Vos, et al. (2006) matched 10 adults for age, education and gender. Both the experimental and control group were administered the *Test of Adolescent Adult Word Finding*. They found significant difference between groups for noun accuracy (p = 0.01), but not for verb naming. Response time for the mTBI group was also significantly longer than for the control group.

Wong, et al. (2010) compared a mTBI group of four male subjects to a control group of 10 subjects matched for age, and education. They administered the *Neurosensory Center Comprehensive Examination for Aphasia, (which* includes the *Token Test*), *The Boston Naming Test, The Test of Language Competence – Expanded, The Word Test – Revised,* and the *Scales of Cognitive Ability for Traumatic Brain Injury.* There were no significant group differences found, but individually two subjects revealed deficits. One mTBI subject scored 2.0 SD below the norm on the token test subtest, and another mTBI subject scored 2.0 SD below the norm on the *Boston Naming Test*.

King, Hough, Walker, (2006) also examined word finding deficits in mTBI subjects. They compared 10 mTBI with 10 controls matched for gender and education level. The administered the *Test of Adolescent/Adult Word Finding (TAWF)* and the *Test of Word Finding in Discourse (TWFD).* This was a pilot study. The mTBI group scored significantly lower on the *TAWF,* but there was no significant group difference on the *TWFD.* The mTBI group demonstrated a significant delay on their response time, *p*= 0.03, for the *TAWF* as well.

Raskin and Rearich (1996) selected 19 subjects with mTBI and matched them for age and education. They controlled for dementia, depression, substance abuse and history of neurological conditions. The subjects were administered a semantic fluency task from the *Boston Diagnostic Aphasia Examination,* and a phonemic word fluency task from the *Multilingual Aphasia Examination.* The subjects were also administered a test of attention, test of executive functioning, and a verbal learning task. Their results revealed the mTBI group to have significantly lower verbal fluency skills for phonemic and semantic retrieval tasks. The experimental group was able to form semantic clusters but not phonemic clusters. The authors proposed that these results may suggest a decrease in processing speed. They did not find evidence to support that the word retrieval deficits were related to executive function or attention deficits. Besides word recall, other studies examined the effects of mTBI on discourse and narratives.

Tucker and Hanlon (1998) recruited eight mTBI subjects, five moderate TBI subjects and five controls matched for age, gender and education level. The subjects were administered the Picture Arrangement subtest for the *Weschler Adult Intelligence Scale – Revised.* There was no significant difference in the accuracy of sequencing the five picture cards, but there was a significant difference in the accuracy of the narrative description of the correct picture sequences, (p = 0.01). There was also a trend of each TBI group to provide fewer implied meanings within this task.

In summary, the bTBI and mTBI literature revealed language deficits in processing speed, word finding, name recall, word fluency, narratives, comprehension of higher level language such as inferences and figurative language and one subject was found to have deficits with auditory comprehension with complex directions. Most of the above studies had small subject pools, weakening their strength. With the exception of the two studies reported by King et al. (2006a, 2006b), none of the other studies reported that they had controlled for hearing loss. Few of the above studies explored comprehension weakness with bTBI. Attention and working memory have been correlated with comprehension concerns, so in theory the blast-injured population, which demonstrates a weakness in attention and memory may also present with comprehension weaknesses. There are few studies that examine comprehension skills.

Whelan, Murdoch, and Bellamy (2007) using a single subject study used both cognitive assessment tools and language assessments, including high-level linguistic assessments such as the *Test of Language Competence-Expanded.* The authors reported cognitive-communication deficits such as attention, lexical access, complex lexical-semantic manipulation both in comprehension and expression, organization and self-monitoring of responses.

Figurative Language skills, Inferencing, Proverbs, and TBI

Figurative language as defined by Nippold (2007), Figurative language requires cognitive abilities (Moran, Nippold, and Gillon, 2006).

Figurative language includes metaphors, similes, idioms, slang, proverbs, fables, ambiguity and sarcasm. Metaphors and similes are figurative language that draws comparisons between two different items. Like verbal reasoning, children demonstrate an increase in their understanding and their use of metaphors and similes throughout school age and adolescence. Similes are usually easier than metaphors to understand. Metaphors that express emotions are more difficult for children to understand than those that express perceptual concepts. Children by age 10 can explain the meaning of common idioms. By age 15 children can explain more difficult idioms, and by 25 years of age, adults can provide detailed descriptions of idioms that they understand well (Moran, Nippold, and Gillon, 2006).

Idioms are both literal and figurative in their interpretations. Slang words are an informal style of speech that is used by different subcultures, and it can change from generation to generation. As with other figurative language styles, idiom comprehension improves with age. Less used idioms that are opaque expressions can be difficult even for adults to understand, but young children can understand common idioms that are transparent in their meanings. Research also reveals that mental images stimulated by idioms become more figurative and these mental images may reflect their actual understanding of the idiom. Understanding of idioms is correlated with cognitive abilities. Idioms are also noted to be easier to understand if scaffolding is in place, such as multiple choice answers, or contextual cues. Slang terms are used predominately by adolescents and mostly within the context of peer conversations. There are big jumps in the variety of slang terms used by teens during their teen years (Moran, Nippold, and Gillon, 2006). Proverbs and fables are the next area of figurative language presented in this paper.

Proverbs express the beliefs, values and wisdom of a particular society. Fables are short stories that end in a proverb or moral. Younger children have the ability to comprehend proverbs and fables if the task is simplified. Children comprehend proverbs sooner that they are able to explain their meanings. Again, as with other figurative language, the understanding of proverbs and fables is correlated with cognitive abilities, it is also correlated with reading and mathematics achievements, as well as with the number of years of formal education. Proverbs comprehension begins in childhood (10 year olds comprehend common concrete proverbs), into the teens (15 year olds comprehend some abstract proverbs), and continues to improve into adulthood (25 year olds can explain abstract, less familiar proverbs). There is a period of time during mid-adulthood that the comprehension of proverbs plateaus, but then it begins to decline during the 60’s and into the 70’s (Nippold, 2007). The final area of figurative language to be addressed is ambiguity and sarcasm.

Metalinguistic language is when language is used in a unique or unexpected form such as sarcasm or ambiguity. In order to understand ambiguity an individual must be able to understand multiple meanings of words. Though ambiguity comprehension increases through maturation, it can still be difficult for young adults and college students. Ambiguity is also related to intelligence, reading comprehension, academic abilities and problem-solving styles.

Sarcasm is more difficult for younger children to understand. Young school age children rely upon intonational patterns to interpret the meaning of sarcasm. As children develop, they begin to use more contextual cues to interpret sarcasm. Adults, at times request clarification of sarcasm. Ten year olds enjoy jokes and riddles that include linguistic ambiguity and they can explain some of these jokes and riddles. They also rely on intonation and context clues to interpret sarcasm. Fifteen year olds can explain the meaning of jokes and riddles that are based on ambiguity, as well as advertisements that use ambiguity. Twenty-five year olds can understand sarcasm in humor and criticism even in the absence of intonational clues, as long as contextual cues are present (Nippold, 2007).

Research focused on Inferencing and TBI is limited. Inferencing is ability to comprehend implied informational text, whether written or verbal, by integrating ones background knowledge. Moran and Gillon (2005) studied six adolescent TBI subjects who had a TBI prior to ten years of age. The results showed that these individuals were able to complete inferencing tasks as well as their age-matched peers when storage demands were minimal. However, when the storage demands were high their abilities to inference as well as their peers was significant (p = 0.042). Moran, Nippold, and Gillon (2006) studied ten TBI adolescent subjects in regards to proverb comprehension. They compared this group to their age-matched peers. The TBI group demonstrated significant difference in their working memory skills when compared to their peer group ($p< 0.05$) with a large effect size ($d=0.79$). There was also a significant difference between the two groups abilities to correctly comprehend the proverbs ($p< 0.01$) also with a large effect size (d=0.47). The authors interpret that working memory demands are high with proverbs and therefore poor working memory skills would cause disruption in the TBI subject's abilities to correctly interpret proverbs.

Prosody and TBI

Prosody is used during spoken discourse of language. Prosody refers to the intonation, rate of speech words, and stress (Rodero, 2015) used in a person's oral speech. Prosody can also be divided into emotional prosody or linguistic prosody. Linguistic prosody encompasses syntactic distinctions, lexical distinctions, and tonal distinctions. Prosody influences the listener's comprehension of the spoken message in several different areas: emotional intent of the speaker, emphasis of important information, clarify ambiguities, producing irony, and increase attention (Wilson & Wharton, 2005; Fry (1958); Rodero, 2015). Intonation can be defined as varying pitch of frequency level used in a spoken message to convey the speaker's mood, emotion, or attitude (Rodero, 2015). Syntactic prosody refers to the use of pausing or intonation phrase boundaries to define syntactic junctures (i.e. *"Let's eat, grandma." "Let's eat grandma.").* Stress, or pitch accents is defined as an increase of volume, pitch, and increased duration of a vowel or syllable (Cevasco & Ramos, 2012). Rate of speech refers to how fast the words in a spoken text are verbalized. The purpose of this section is to present the information in the literature about *stress*, its importance to the comprehension of verbal language, and what if any research existence within the traumatic brain injured population. Would bTBI present with comprehension deficits in the understanding of prosodic stress tasks?

There are three recent studies that focused upon comprehension of emotion through prosody. This included intonation and stress or pitch accents. Interestingly these three studies all focused specifically upon the head injured population.

Marquardt, Rios-Brown, Richburg, Seibert, and Cannito (2001) completed two studies. The first was to evaluate if TBI subjects were able to identify the emotion in congruous and ambiguous sentences. The TBI subjects were matched with typical peers (mean age of 31.2). The TBI subjects were 10 right-handed males (mean age of 30.0) post non-penetrating head injuries residing in a residential rehabilitation facility. They were assessed as having low average to below average intelligence (67-90 full scale scores on Wechsler Adult Intelligence Scale) and placed at a level VII or VIII on the Rancho Los Amigos Scale. The subjects heard sentences with matched prosody and facial expression (congruous) and unmatched (ambiguous) i.e. “It’s a wonderful surprise” stated with happy prosody but an angry face. Then the task was repeated but this time without the visual of the facial expression, and the prosody matched or did not match the message to assess their ability to identify affect. Significant results, with alpha set at .05, indicated that the TBI group had reduced ability in identifying the affect presented in congruous and ambiguous sentences regardless of the presentation mode.

The authors second study examined seven TBI right-handed males with non-penetrating head injuries. Their mean age was 29.1, full scale intelligence score range was from 76-111, and time post injury was a mean of 5.76 years (range of 10 months to 15 years). The control group of peers mean age was 28.7 years. This study wanted to extend the first study by adding in the subject’s ability to identify and produce verbally neutral sentences with paralinguistic affective cues. So the sentences did not include emotional words. These results were also significant, demonstrating that the TBI subjects have not only difficulty identifying emotional prosody but demonstrated reduced ability to produce emotional prosody in their voices (Marquardt, Rios-Brown, Richburg, Seibert, & Cannito, 2001).

Karow, Marquardt, and Levitt (2013) were also interested in investigating TBI subject's processing of prosody in respects to their ability to identify the emotion in the message. They expanded the previous study by separating their TBI subjects into four categories by depth and location of lesion: left cortical, right cortical, left subcortical-cortical, and right subcortical-cortical. The authors were also interested in identifying the trends between these groups as to whether they would rely more on the prosody, or the facial expressions to determine the speaker's emotional intent. They recruited 5 subjects for each category and 5 healthy subjects for the control group. The mean age for each group ranged from 56.8-63.6 years. There were 10 females and 15 males. All TBI subjects were at least 6 weeks post the injury. Their results demonstrated that the healthy subjects were significantly more accurate than the brain injured groups combined in interpreting a speaker's emotions. The healthy speakers was noted to rely more on facial expressions over speech prosody when the speech prosody did not match the facial expression. The left cortical group performed similar to the healthy group with no significant differences. The right cortical group also performed similar to the healthy except when the speech only task was presented, suggesting they rely more on the visual expression. The left subcortical group demonstrated significant differences between the healthy and cortical groups on the first task when the verbal text and prosody did not match. On the second task were there were no verbal text emotional words and the prosody was matched, or not matched with the facial expressions this group performed similar to the healthy and cortical groups. The right hemisphere subcortical group scored significantly lower than all the other group performances. This suggests that the subcortical right hemisphere is important for perceiving emotional prosody.

Syntactic processing is also termed prosodic boundaries. Prosodic boundaries are important in the role of comprehending ambiguous sentences (i.e. *"Let's eat, grandma." "Let's eat grandma.").* Speakers use prosodic breaks to demonstrate where a coma in written text would occur. These prosodic breaks are important to clarify ambiguity. Most studies on this topic have examined the importance of prosodic breaks in the comprehension of syntactic disambiguation. Snedeker and Trueswell (2003) for example used a barrier task to assess the importance of prosodic breaks to complete direction following tasks that were ambiguous (i.e. "Tap the frog with the flower".). Depending where you put the prosodic break you could have the subject tapping a frog that has a flower, or tapping a frog with a flower.

How do speakers produce the prosodic break? This is a question Kraljic and Brennan (2005) addressed. They had subjects in their study take turns giving each other directions using ambiguous instructions similar to the first study discussed. They found the speakers marked the syntactic boundaries by lengthening the word before the prosodic boundary.

Research for identifying which hemisphere is responsible for prosody boundaries is inconclusive. Some studies identify left hemisphere activation in fMRI studies (Walker, et al. 2002), and others have found both left and some right hemisphere activation (Baum & Dwivedi, 2003; Meyer et al. 2004). The area's most activated were the mid to anterior superior temporal cortex bilaterally (Meyer et al. 2004).

Conclusion

Discourse is conversational language, which includes more than just semantics and syntax. Discourse also includes inferencing, decoding of prosodic signals, and activation of memories. Prosodic stress facilitates inferencing by highlighting important information in a sentence (Wilson & Wharton, 2006). Stress also facilitates comprehension when a listener has decreased language processing (Cohen & Faulkner, 1986). In addition, stress can facilitate comprehension when a listener has decreased working memory capacity (Cevasco & Ramos, 2012). Prosodic boundary markers also increase comprehension specifically with ambiguous sentences (Cevasco & Ramos).

Decreased comprehension due to inability to recognize stress markers would then be expected to appear in several population groups. Autism for instance. People with autism experience difficulty with emotion and attitude prosody, contrastive stress, and intonation (Wilson & Wharton, 2006). Other populations with difficulty with comprehension of, or use of emotional prosody include Parkinson's disease, schizophrenia and other mental health disorders, as well as dementia (Zupan, Neumann, Babbage, & Willer, 2009). Traumatic brain injured population have been found to have difficulty with both production and comprehension of emotional prosodic stress (Karow, Marquardt, & Levitt, 2013; Zupan et al., 2009; Marquardt, Rios-Brown, Richberg, Seibert, & Cannito, 2001). Finally, healthy elderly were assessed for the benefits of lexical stress markers. The elderly's auditory comprehension improved more than the young healthy adults from lexical stress placement (Cohen & Faulkner, 1986).

Future research is needed to assess the benefits of syntactic prosody and lexical stress. Little research has been completed in this area, specifically with the mild traumatic brain injury population. As to date the research has focused upon the comprehension of emotions through prosody, but not the aspect of how syntactic linguistic prosody can facilitate processing of language. Mild TBI subjects demonstrate decreased working memory, processing speed, and attention. Since these cognitive skills are correlated with syntactic and linguistic prosody it would be hypothesized that mTBI would then present with syntactic and linguistic prosody deficits. Empirical data is lacking in this area.

Working Memory, Attention, and Language.

Moser, Fridriksson, and Healy (2007) examined the correlation with sentence comprehension and working memory. They used 27 English as the first language right handed females in their early to mid-twenties. Using Pearson correlation coefficients and significant correlation (p = 0.00) was found between the reaction times for nonverbal working memory and sentence parsing tasks. The correlation between lexical decision and working memory was not significant (p = .09), nor was there a statistically significant correlation between the reaction times for lexical decision and sentence parsing (p = .05). (Alpha was set at .01). A moderate correlation was found between the nonverbal working memory task and sentence comprehension, which suggests that these two processes are related. There are other possible correlations between cognitive skills and communication.

Hartley, (1995); Sohlberg, (2009); and Sohlberg and Mateer, (2001) (as cited in Cornis-Pop et al., 2012) reported numerous communication skills that may be impaired due to cognitive changes in mTBI. The cognitive changes include attention deficits, which may cause difficulty with learning new information, difficulty conversing when there is background noise, or distractions, difficulty when reading complex or lengthy material, difficulty shifting or maintaining a topic. Speed of processing may delay responses during conversation, or make it difficult to comprehend rapid rate of speech, maintain a topic, or cause an increase in pause time during conversations. Memory deficits may cause difficulty in recalling instructions or messages, difficulty in learning new information, remembering names, recalling details, maintaining a topic, repetition tasks, cause lack of coherence in conversation, or comprehending abstract language.

Attention has been reported as a lasting deficit from bTBI (VADoD, 2009) and mTBI (Cicerone, 1996), and post concussive syndrome (Crawford, 2007). How does it relate to language deficits? First, we need to define attention. Attention is a necessary neurobiological function that allows humans to select what we perceive as the essential information in our environment. This may be external or internal environment and attention may be sustained for an extended period of time or short period of time (Purves, et at., 2008, p. 249). There are several types of attention. The most common known types of attention are selective attention, visual spatial attention, exogenous attention, divided attention, and sustained attention. Selective attention is best explained through the “cocktail party effect”, which refers to one’s ability to maintain focused upon a conversation in the mist of multiple conversations occurring simultaneously around them (Purves, et at., 2008, p. 251).

Exogenous attention refers to our ability to acknowledge change in our environment (i.e. the occurrence of a loud noise, or a quick movement), but continue to maintain our attention to another stimuli (Purves, et at., 2008, p. 261). Divided attention refers to one's ability to focus on more than one task at a time (Chan, 2001). Multi-tasking is a common term for this type. Sustained attention is the ability to maintain arousal, or alertness of cognitive processing (Chan, 2001). There are also subtypes in the different areas of attention; for example, auditory spatial attention is part of selective attention. This refers to when there is a simultaneous presentation of two or more sources of auditory information (Purves, et at., 2008, p. 272). Different areas of the brain have been associated with attention.

Areas on the brain associated with auditory attention on PET scans are the lower bank of the Sylvian Fissure (Purves, et at., 2008, p. 276), and on fMRI's the primary auditory cortex in Herschel's gyrus and Superior Temporal gyrus were activated (Purves, et at., 2008, p. 277). Sustained attention has been correlated with the amygdale, right lateral midfrontal cortex and front and parietal cortices (Chan, 2001). Selective attention has been associated with the frontal lobes, thalamus, striatum and anterior cingulated cortex (Chan, 2001). Divided attention has been correlated with the superior aspect of the left pre-frontal cortex, and right occipital regions (Chan, 2001). Though the frontal lobes are accepted as the most imported section of the brain for attention, other parts of the brain may have an important role as well.

Chan (2001) states in his meta-analysis other portions of the brain that have important roles in attention. The posterior parietal lobe may affect shifting of attention. Superior colliculus may be associated to shifting of visual attention. The thalamus may be important for exogenous attention. The temporal lobe may affect secondary functions of attention such as orientation, automatic processing, and processing speed. How does this relate to mTBI or bTBI? These subjects suffer from axon shearing effects in the above cortical areas. Attention deficits are a frequent complaint with this population.

Sustained attention and divided attention are both reported in the literature as being impaired in the mTBI population (Chan, 2001). Sustained attention deficits are thought to be secondary to decreased visual arousal responses, but divided attention deficits are thought to be secondary to reduced controlled processing, or difficulty in shifting attention (Chan, 2001). Controlled processing is also termed central executive functioning. Central executive functions has a limited capacity, which can be impaired when over taxed. The overload could interfere with the brains ability to rehearse or allocate information. Attention control theoretically may be a top-down system. The controlled processing allows information from various parts of the brain to be integrated and control attention through regulating the intensity of attention and selectivity of attention (Chan, 2001). Chan states “Normal attentional mechanisms require the interaction of the intact intensity and selectivity of attention as well as the attentional control processing.

Therefore, it is believed that the normal functioning of the whole attentional system will be affected whenever there is a defect in only one component of the attentional mechanisms" (p. 90).

In summary, approximately 30 percent of our military personnel involved in the Iraqi or Afghanistan wars have sustained blast injuries. Blast traumatic brain injuries cause white matter neural changes. Thought the research is not robust on bTBI it is in post-concussion syndrome, which is similar to bTBI. Both of these disorders have common neurocognitive symptomology one of which is attention deficits and auditory processing deficits. Attention deficits have been linked with PCS are sustained attention and divided attention. Attention is necessary for visual and auditory processing. Could attention deficits interfere with auditory comprehension?

Word finding, processing speed, and discourse/narratives have been examined in the non-blast injury literature, but limited studies examined auditory comprehension and those that did have limited subject pool. Blast injuries are known to affect air organs such as the ear and lungs (Moore & Jaffee, 2010), and auditory processing deficits is listed to be in the top five problems recorded with bTBI veterans (Roth, 2012). They suggest that it may be probable that we could find comprehension deficits in the bTBI population. Attention deficits also are reported to negatively impact processing speed which may interfere with high level comprehension. Massoro's (1975) information processing theory states (as cited in Bellis, 2003) that comprehension depends on the extraction of information at different stages of processing. The “bottom up” term refers to the encoding of auditory signals for the auditory nerve to the brain prior to the higher-order cognitive and linguistic operations at the cortical level (Bellis, 2003). The “top-down” term refers to the influence of the higher-order factors such as memory, attention, and linguistic operations. Both “top-down” and “bottom-up” processes are important for a person to process information (Bellis, 2003). Therefore, it is reasonable to expect there may be auditory comprehension deficits in the bTBI population. Exploratory research to examine possible complex auditory comprehension deficits in the bTBI population is warranted and needed.

Theoretical Framework

Within the literature a gap is found with the lack of research on auditory comprehension skills in the blast injured population. The areas of weaknesses confirmed in the literature, such as attention, working memory, speed of processing, and auditory processing, hearing and vision acuity would all suggest that there may also be auditory comprehension weaknesses. The theoretical frames that might support the fact that the bTBI population may present with auditory comprehension deficits are Massaro (1975) information processing theory, which states that both bottom-up and top-down important for language skills and the extended language network (Fitch, 2010).

Extended language is defined as the combination of cognitive processes and higher-level language comprehension (Fitch, 2010). These cognitive processes include inferencing, Theory-of-Mind, executive functions and working memory. Inferencing requires the integration of one's background knowledge and the current text to draw information. Theory-of-mind refers to one's ability to understand or acknowledge others points of view, perspectives, motives, emotions, thoughts and/or beliefs about the world. Higher-level language comprehension refers to the comprehension of connected text, or pragmatic interpretations including figurative language (metaphors, idioms, similes), and inferencing (Fersti, Neumann, Bogler, & von Cramon, 2008). Extended language is beyond the comprehension of words and sentences. There are several models that address the complexity of extended language comprehension, the extended language network (Fersti et al. 2008), faculty of language in a broad sense (Fitch et al., 2005), and information processing theory of Massaro (1975).

Fersti et al. (2008) refers to an extended language network, which is involved in the comprehension of language. Fersti et al. explains how language comprehension requires more than just comprehension of words and sentences, but also cognitive processes such as theory of mind, attention, inferences, and self-monitoring to be sure that comprehension matches the communicative situation. All these processes require numerous brain regions to be activated thus resulting in what Fersti et al. refer to as "an extended language network (ELN). These authors demonstrated their model by completing a meta-analysis of neuroimaging studies on text comprehension. They examined twenty-three neuroimaging studies. They looked at four areas, resting baseline with test comprehension, non-language baseline (speech played backwards), coherent vs. incoherent language, and comprehension of metaphors. Results revealed an overlap for three of the four areas in the anterior temporal lobe, bilaterally. Each area also showed additional brain activation including the posterior cingulated cortex for coherence of text and other areas of the fronto-temporal regions. Thus, numerous areas of the brain are required for language comprehension, as other studies have also demonstrated since the publication of this meta-analysis (Oblese & Kotz, 2010).

The information processing theory of Massaro (1975) is a connectionist model that suggests that comprehension relies on the extraction of information at different stages of processing, which requires interpretation of both sensory and cognitive information simultaneously and sequentially. Comprehension occurs at both the peripheral and the cortical levels. Peripheral or sensory information includes auditory, visual and tactile data, and high-level cognitive skills include attention, speed of processing and memory.

Fitch's (2005) *faculty of language in a narrow sense* consists of all the mechanisms that partake in language acquisition as use. These mechanisms include cognitive processes, such as memory, theory of mind, and inferencing, plus audition, vision, sequencing, speech perception and vocal production.

Framework and Language Deficits Connections

The common factor in these models is that language requires multiple domains. How this applies to the TBI subject is that this population suffer from diffuse axon injuries that affect numerous parts of the brain. These injuries combined could affect the functioning of successful language from numerous sources, such as poor attention, memory, auditory or visual, or theory of mind. For example if an individual has decreased hearing then that individual may have increased difficulty with speech discrimination which in turn will affect their ability to interpret correctly a spoken message. The tone or inflection in a speaker's voice may also be missed, which also may interfere with the listener's ability to correctly comprehend a spoken message (Bellis, 2003). Auditory processing deficits will also interfere with a listener's ability to process auditory messages especially in the presence of background noise, or if the verbal message is lengthy, then part of the message is lost. Visual deficits may have a similar impact on comprehension.

Visual deficits may affect a person's ability to correctly interpret body language, facial expressions, and visual cues that assist in interpreting certain phonemes. If a subject has a duel sensory impairment, both visual and auditory impairments, then they are at a higher risk to have difficulty with comprehension of oral language. Cognitive deficits may also interfere with language comprehension.

Cognitive skills such as attention, memory, theory of mind, and speed of processing, are all important for successful language functions. There are several different forms of attention; selective attention and divided attention. Selective attention is best explained as the “cocktail party attention”. This is when one is able to hold or stay focused upon a conversation while there are other conversations occurring around them at the same time. Divided attention refers to one’s ability to focus upon two or more tasks simultaneously. This is also referred to as multi-tasking. Interference with one’s sustained attention during instructions or a conversation will interfere with comprehension. The interruption of attention may result in missed information, or an inflection change, which changes the meaning of the message, therefore impeding comprehension (Cornis-Pop et al. 2012, Kristensen, Wang, Petersson, & Hagoort, 2013).

Discourse is conversational language, which includes more than just semantics and syntax. Discourse also includes inferencing, decoding of prosodic signals, and activation of memories. Prosodic stress facilitates inferencing by highlighting important information in a sentence (Wilson & Wharton, 2006). Stress also facilitates comprehension when a listener has decreased language processing (Cohen & Faulkner, 1986). In addition, stress can facilitate comprehension when a listener has decreased working memory capacity (Cevasco & Ramos, 2012).

Speed of processing is another cognitive process needed for comprehension. Speed of processing refers to the rate of speed one is able to interpret information and respond. Deficits in this area may result in difficulty with maintaining a topic during discourse, reduce one's response time to questions, or limit one's ability to accurately comprehend rapid speech (Cornis-Pop et al. 2012).

Theory of Mind deficits may affect language comprehension because it will interfere with one's ability to integrate the current text with one's ability to see or understand other's points of views, feeling, or intent. This is especially important for inferencing. Finally, memory has an important role in language skills. Comprehension and discourse both rely on memory capacity and recall. Memory includes many parts, such as semantic memory, episodic memory, procedural memory, and working memory. Limitations in memory abilities may interfere with language comprehension, inferences, ambiguities, and indirect requests, learning of new information, and one's ability to retain complex directions (Cornis-Pop, 2012; Moser, Fridriksson, & Healy, 2007; Gaudreau, Monetta, Macir, Laforce, Poulin, & Hudon, 2013; Wong, Murdoch, & Whelan, 2010). Working memory, for example has limited capacity element (Baddeley, 2003). This limited capacity explains how auditory information may be lost. If an individual has a reduced amount of capacity in their memory then this individual would need to use more energy to process information. This switch in energy would interfere with this individual's ability to retain all information heard leading to lost information, which would then impair comprehension of the verbal message. Therefore, a running conversation, or retention of complex directions could be impaired.

Summary

In conclusion, successful language functioning requires speed of processing, comprehension of words and sentences, selection, organization and planning of ideas, theory of mind, memory, attention, and vision and audition all working simultaneously and sequentially. Any breakdown or interference and any level may impair successful language functioning including comprehension. There is a network of brain activation that connects all of these functions. Mild TBI subjects who have axon shearing will have impaired brain activation, which in turn may interfere with any of the above skills need for successful language, such as comprehension of language. Language comprehension may encompass many different domains, such as syntactic, prosodic, and semantic. Literature has demonstrated that mTBI subjects from sports and motor vehicle accidents demonstrate comprehension deficits with ambiguous sentences, inferences, and figurative language (Barwood, & Murdoch, 2013; Wong, Murdoch, & Whelan, 2010) and comprehension of emotional prosody (Karow, Marquardt, & Levitt, 2013;

Zupan, Neumann, Babbage, & Willer, 2009). High level language comprehending within the domains of ambiguous sentences, and inferences has not been assessed in the blast TBI military population, nor has discourse comprehension, or lexical prosody. These areas of language functioning is important for daily communication skills and research would facilitate speech/language therapists in their assessment and treatment of this population. It is important not only for treatment, but for patient and family education as well. Assessment for these domains, since they have been identified as weaknesses in the mTBI population in the sports and MVA arena, would help close the argument as to whether the blast injured group does or does not exhibit cognitive communication language deficits. Research is warranted to identify if there are high level auditory comprehension deficits with veterans who have incurred blast injuries. In addition, if there are comprehension deficits in the bTBI population, can these weaknesses be correlated with the frequency, or intensity of blasts the soldier was exposed to, and then is it possible that these language skills might be used as a diagnostic tool to identify subjects with bTBI?

The purpose of this study is to look below the surface and examine if blast exposed veterans have difficulty with higher level language skills, such as ambiguity, inferencing, figurative language, and complex sentence comprehension, which are highly correlated with decreased cognitive functions of working memory, speed of processing, and attention. The results are intended to assist the VA system in providing the best possible services to facilitate these veterans in transitioning successfully back into society for a productive post-service life.

Research Questions

1. Do post-acute blast exposed veterans demonstrate *attention* deficits when compared to control subjects?

   Hypothesis: Non-blast veterans will perform better than bTBI veterans on *attention* tasks.

2. Do post-acute blast exposed veterans demonstrate *working memory* deficits when compared to control subjects?

   Hypothesis: Non-blast veterans will perform better than bTBI veterans on *working memory* tasks.

3. Do post-acute blast exposed veterans demonstrate *processing speed* deficits when compared to control subjects?

   Hypothesis: Non-blast veterans will perform better than bTBI veterans on *processing speed* tasks.

4. Do post-acute blast exposed veterans demonstrate *auditory processing* deficits when compared to control subjects?

   Hypothesis: Non-blast veterans will perform better than bTBI veterans on *auditory processing* tasks.

5. Do post-acute blast exposed veterans demonstrate *auditory comprehension* deficits on *inferencing* tasks when compared to controls?

Hypothesis: Non-blast veterans will perform better than bTBI veterans on *inferencing* tasks.

5a. Is there a correlation between their *inferencing* abilities and their *attention skills*?

Hypothesis: There will be a correlation between inferencing and attention skills.

5b. Is there a correlation between their *inferencing* abilities and their *working memory* skills?

Hypothesis: There will be a correlation between inferencing and working memory skills.

5c. Is there a correlation between their *inferencing* abilities and their *speed of processing* skills?

Hypothesis: There will be a correlation between inferencing and speed of processing skills.

5d. Is there a correlation between their *inferencing* abilities and their *auditory processing* abilities skills?

Hypothesis: There will be a correlation between inferencing and auditory processing skills.

6. Do post-acute blast exposed veterans demonstrate *auditory comprehension* deficits on *ambiguity* skills?

Hypothesis: Non-blast veterans will perform better than bTBI veterans on *ambiguity* tasks.

6a. Is there a correlation between their *ambiguity* abilities and their *attention* skills?

Hypothesis: There will be a correlation between ambiguity abilities and attention skills.

6b. Is there a correlation between their *ambiguity* abilities and their *working memory* skills?

Hypothesis: There will be a correlation between ambiguity abilities and working memory skills.

6c. Is there a correlation between their *ambiguity* abilities and their *speed of processing* skills?

Hypothesis: There will be a correlation between ambiguity abilities and speed of processing skills.

6d. Is there a correlation between their *ambiguity* abilities and their *auditory processing* abilities?

Hypothesis: There will be a correlation between ambiguity abilities and auditory processing skills.

7. Do post-acute blast exposed veterans demonstrate *auditory comprehension* deficits on *syntactic prosody* when compared to controls*?*

Hypothesis: Non-blast veterans will perform better than bTBI veterans on *syntactic prosody* tasks.

7a. Is there a correlation between their *syntactic prosody* comprehension abilities and their *attention* skills?

Hypothesis: There will be a correlation between syntactic prosody comprehension and attention skills.

7b. Is there a correlation between their *syntactic prosody* comprehension abilities and their *working memory* skills?

Hypothesis: There will be a correlation between syntactic prosody comprehension and working memory skills.

7c. Is there a correlation between their *syntactic prosody* and their *speed of processing* skills?

Hypothesis: There will be a correlation between syntactic prosody comprehension and speed of processing skills.

7d. Is there a correlation between their *syntactic prosody* and their *auditory processing* abilities*?*

Hypothesis: There will be a correlation between syntactic prosody comprehension and auditory processing abilitites.

8. Do post-acute blast exposed veterans demonstrate *auditory comprehension* deficits on *figurative language* skills when compared to controls?

Hypothesis: Non-blast veterans will perform better than bTBI veterans on figurative language tasks.

8a. Is there a correlation between their *figurative language* comprehension abilities and their *attention* skills?

Hypothesis: There will be a correlation between figurative language comprehension and attention skills.

8b. Is there a correlation between their *figurative language* comprehension abilities and their *working memory* skills?

Hypothesis: There will be a correlation between figurative language comprehension and working memory skills.

8c. Is there a correlation between their *figurative language* and their *speed of processing* skills?

Hypothesis: There will be a correlation between figurative language comprehension and speed of processing skills.

8d. Is there a correlation between their *figurative language* and their *auditory processing* abilities*?*

Hypothesis: There will be a correlation between figurative language comprehension and auditory processing abilities.

9. Is there a correlation between the presence of an *auditory comprehension* deficit and the *number of blasts* the subject was exposed to?

Hypothesis: There will be a relationship between auditory comprehension deficits and the number of blasts the veteran experienced.

10. Is there a correlation between the presence of an *auditory comprehension* deficit and the *intensity* of the blasts the subject was exposed to as defined by the *Boston Assessment of TBI-Lifetime* (2013)?

Hypothesis: There will be a relationship between auditory comprehension deficits and the blast severity level a vet presents with as defined by the *BAT-L.*

Chapter III

Methods

Subjects

This is a nonprobability sampling- convenience sample of Veterans who were deployed in OEF/OIF conflicts and enrolled in the VA NJ Healthcare System.

Thirty-two VA veterans from the Iraq or Afghanistan conflicts. Age(s) of subjects: 21.0 – 45.0 years will be recruited. By age 21 our language skills are mastered and higher level language skills are mastered between 19 – 25 years of age (Nippoldi,1951), depending on individual differences. Forty years of age was chosen to avoid any regression in language and cognitive abilities that may be part of the normal aging process. In addition, most veterans receiving VA care are in the 20-39 year old range (Batten & Pollack, 2008).

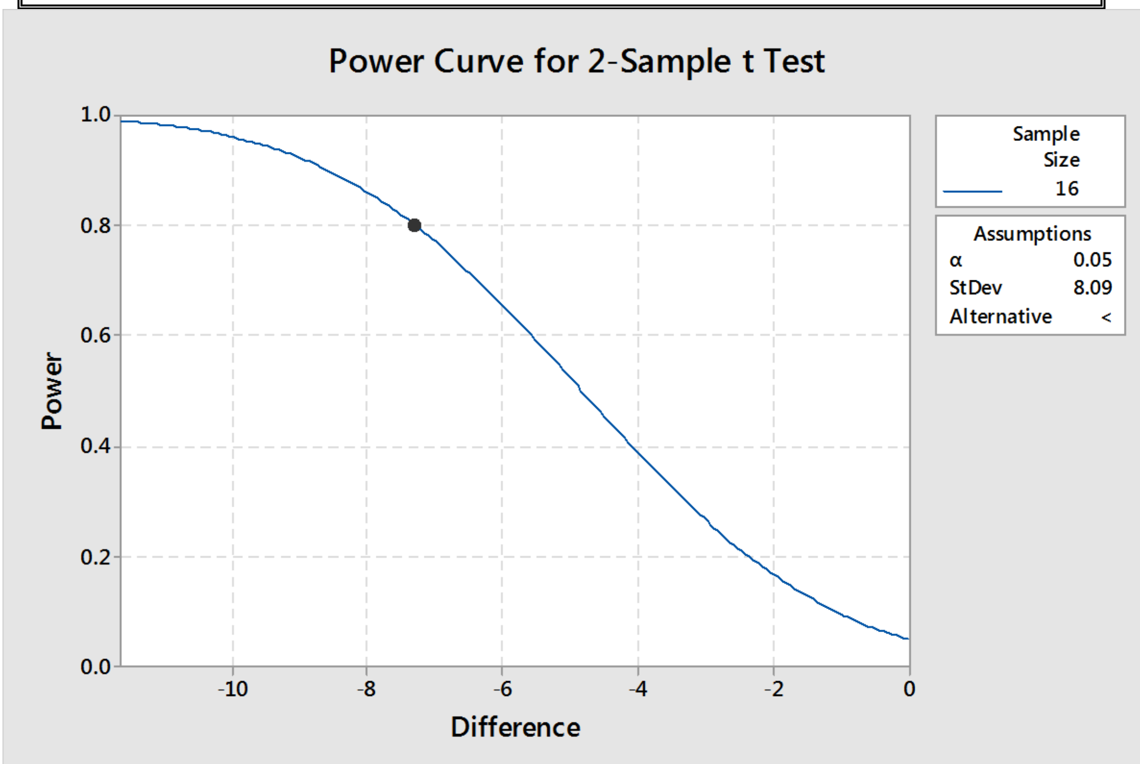
Number of subjects was achieved through g-power statistics using MiniTab software.

Figure 3. G-Power Sample Size

α = 0.05 Assumed standard deviation = 8.09

Sample Size	Power	Difference
16	0.8	-7.27800

The sample size is for each group.



Based upon the study by Barwood and Murdoch, (2013), using their standard deviations obtained for the three subtests of ambiguity, inferencing, and figurative language, with the power set at 0.80 and alpha set at 0.05, a sample size of 16 is recommended by MiniTab version 17 software program.

Subjects will be recruited from the Bloomfield VA Vet Center. The veterans will be provided with the recruitment flier by the Vet Center's staff psychologists.

Inclusion Criteria:

Experimental group- Sixteen Iraq or Afghanistan war veterans exposed to 1 or more blasts and within 100 meters of the blast. The subjects are to be 3 months or more post their last blast exposure. Definition of bTBI - Exhibited a transient change in mental status due to an explosive event including one or more of the following: low of consciousness for less than 30 minutes; retrograde or posttraumatic amnesia for less than 24 hours; alteration in mental status at the time of the injury (dazed, disoriented, confused); and a Glascow Coma Scale score of 13-15 after the first 30 minutes of blast but within the first 24 hours of the blast (if available), high-school diploma or GED; proficient in English. Veterans will be asked to reframe from drinking alcohol for 24 hours prior to testing session. This will be by self-report.

Control group- Sixteen Iraq or Afghanistan war veterans absent of blast exposures, high-school diploma or GED, proficient in English matched in age with the control group. Veterans will be asked to reframe from drinking alcohol for 24 hours prior to testing session. This will be by self-report.

Exclusion Criteria:

No history of seizures or moderate to severe head injuries; mild head injuries from MVA or falls; prior serious medical illness', such as cerebrovascular accident and myocardial infarction; current active suicidal and/or homicidal ideation, intent, or plan requiring crisis intervention; current

DSM diagnosis of bipolar disorder, schizophrenia, or other psychotic disorder, (except PTSD); or cognitive disorder due to general medical condition other than TBI; hearing loss no greater than 25dB.

Procedure

This study is an Exploratory: Cross-Sectional; Correlational; Prospective; Cohort Study Design.

“Exploratory research is the systematic investigation of relationships among two or more variables.” “Diagnostic and prognostic factors are identified through exploration of their relationships with results of specific tests and patient outcomes.” (Portney, & Watkins, p. 277, 2009). This study is investigating if a specific deficit does or does not exist in a certain population.

In this study we are investigating in the present time, which makes it prospective research. These veterans have shared a common event, blast exposure, which is prevalent in the Iraq and Afghanistan theaters. It is not yet known if these blast exposures affect high level auditory comprehension abilities. This qualifies this study as a cohort study. Cohort studies are more effective for studying single disorders, which is the design of this current study.

This study is examining the subjects at one point in time, which makes this cross-sectional research. Finally, this study is measuring an association among the variables, which fits the correlation process.

Each subject will be administered the *Boston Assessment of Traumatic Brain Injury-Lifetime (BAT-L)* to obtain pertinent history regarding head injuries; *Consonant Trigrams Test* to assess working memory skills, *Symbol Digit Modality Test* to assess processing speed, *Trail Making Test-form B,* to assess attention skills, *SCAN-3* to assess auditory processing skills, *Clinical Evaluation of Communication Skills-5 Metalinguistics* to assess higher level auditory processing skills of figurative language, ambiguity, and inferencing, *Communication Assessment of Spoken Language* to assess higher level auditory processing skills of sentence comprehension. A nonstandard test of prosodic pausing for ambiguity will also be administered. In addition each subject will have a hearing screening to reach inclusion criteria.

Veterans will be identified at the Bloomfield Vet center by the physiologists, American Legions and Veterans of Foreign Wars centers commanders. The veterans will be invited to join the study by providing them with the recruitment flier. A recruitment letter explaining the purpose of the study, the time commitment, types of tasks included in the study, the incentives to be provided (mileage reimbursement $0.50/mile, and $10.00 gift certificate to Duncan Donuts), and the primary investigators contact information.

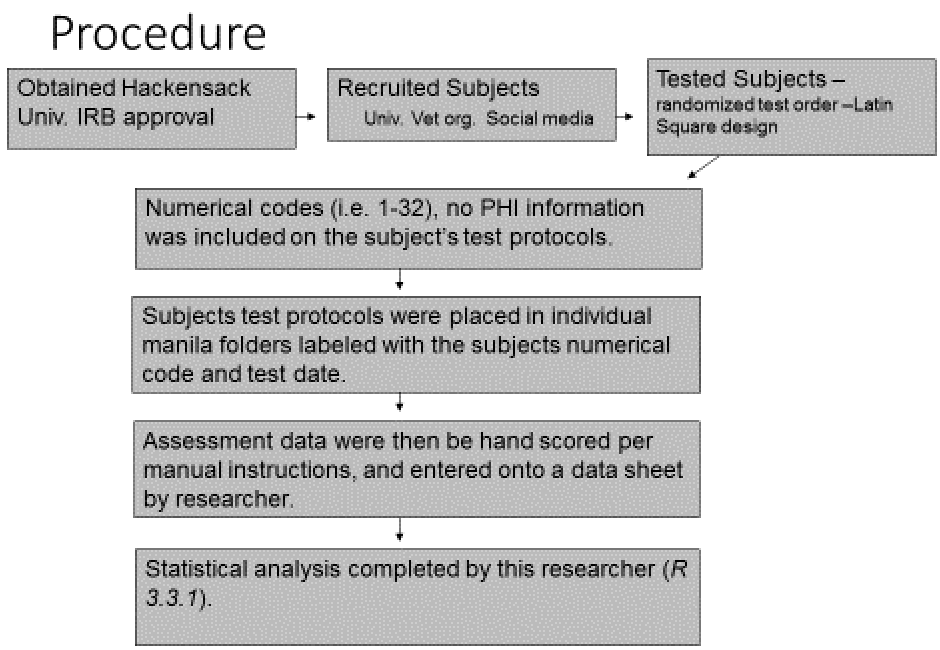
If the subject meets inclusion/exclusion criteria they will be invited to join this study. After receiving the subject's permission to partake in this study, a single evaluation session of 2-3 hours will be scheduled by the investigator.

During that session, the above tests will be administered. Subjects will be informed of the instructions for each individual test as each test is administered. The subject will be informed that between the tests, approximately each half hour, the subject will be given the option to take a 5 minute break. They will be reminded that the testing will take between 2-3 hours. Breaks will be provided as needed at 30 minutes intervals at the conclusion of a test, not in the middle of a test. The hearing screening will be conducted first to secure inclusion criteria, after which the order of assessments will be randomized with each subject, using a random table method, to avoid a fatigue effect. The interview tool, *Boston Assessment of Traumatic Brain Injury-Lifetime,* will be administered last. This is to decrease examiner bias by attempting to blind the tester as to whether or not the veteran is in the experimental or control group. When all testing is completed the subject will be presented with their incentive.

Assessment data will then be hand scored and entered onto data sheet. Subjects initial intake for will be given a numerical code (i.e. 1-30). No names will be included on the subject's test protocols. Each subjects test protocols will be placed in individual manila folders labeled with the subjects numerical code and testing date. All data will be secured in a locked file cabinet in Dr. Balasubramanian's office in McQuaid Hall at Seton Hall University. Data will be scored according to each individual test's instructions. This investigator will be scoring and analyzing the protocols.

Statistical analysis will follow. Initially, a test of normality will be completed such as the Shapiro-Wilk test. On the assumption that normality will not be obtained the data will be analyzed using nonparametric statistics. To determine results of research questions #1, 2, 3, 5, 6, 7, 8 (i.e. "*Do post-acute bTBI veterans demonstrate auditory comprehension deficits on high level comprehension tasks?"*) *t*-test for independent samples will be used to compare the control and experimental groups. For the remainder of the research questions (#1a-1d, 2a-2d, 3a-3d, 4a-d, 9, and 10) a *t*-test for the correlation coefficient shall be used, such as a Pearson's correlation.

Figure 4. Flow Chart of Procedure



Materials

Clinical Evaluation of Language Competence-Expanded 5 – Metalinguistics*; (*Wiig, E. & Secord, W., 2014); Making Inferences and Figurative Language subtests.

"Making Inferences subtest requires the examiner to show the subject a page from the Stimulus Book which contains two statements followed by four response options. The first statement is a lead-in sentence that describes a context or initiates a chain of events. The second statement is a concluding sentence. The four response options provide potential inferences that could be made given the lead-in and concluding statements. The examiner reads the lead-in and response options out loud. The subject is required to identify

two responses that best explain the concluding sentence. The subject is then asked to provide a third possible explanation not provided in the choices." (Wigg, and Secord, 2014).

"Figurative Language subtest requires the subject to explain figurative expressions that are matched with a situation (context). The subject is then presented with four more figurative expressions and they are asked to identify one of the four that has a meaning close the first expression presented. Each foil is presented orally and visually." (Wigg, and Secord, 2014).

"*Multiple Meanings* subtest (previously named Ambiguous Sentences) requires the examiner to show the subject a sentence in the Stimulus Book that contains ambiguity at either the word or sentence level. The clinician reads the sentence aloud and asks the student to describe two meanings for each sentence." (Wigg, and Secord, 2014).

<u>Reliability</u>-

Internal Consistency Reliability Coefficients

Making Inferences- .83;

Figurative Language- .90;

Multiple Meanings - .89;

These scores are considered "good" rates.

Standard error of Measurement is 3 for the tests and 15 for composite scores.

Critical values for confidence intervals are set at 68%, 90%, and 95%.

Inter-Scorer Agreement over three consecutive weeks was .95 for Making Inferences, Multiple Meanings, and Figurative Language subtests (*CELF-5 Metalinguistics Manual*, 2014).

Validity –

Internal Structure-

Intercorrelational Studies-correlations were moderate at the test level (.41 - .63) and moderate to high at the index level (composite scores) (.43 - .90).

Goodness of Fit Statistics for Confirmatory Factor Analysis using both one-factor model and the two factor model revealed close fit to the data, and thus providing support for the categorization of language competence into two domains, meta-pragmatic and meta-semantic ability.

Correlation with the *Test of Language Competence* – Expanded

The *TLC-E* is the predecessor of the *CELF – 5 Metalinguistics* test. There was a high positive correlation (.81) between the two tests indicating that they both measure similar language behaviors. However, there is a difference in the normative populations resulting in slightly higher scores on the CELF-5 Metalinguistics.

Comprehensive Assessment of Spoken Language – Elizabeth Carrow-Woolfolk (2008): Sentence Comprehension subtest

The Sentence Comprehension subtest evaluates auditory comprehension of sentence pairs with different sentence structures and determine if the two different sentences have the save meaning. The sentences may vary by having embedded declarative s, which may contain one or more clause constructions, and grammatical structures such as active or passive voice, direct or indirect objects, possessive forms, prepositions, or negatives. Word order may be altered to change the meaning as well.

Reliability –

Internal Consistency: The reliability coefficients of the test were computed with Rasch split-half method by age groups; Sentence Comprehension – (.64).

Inter-scorer Agreement: very high ranging from (.98 to .99).

Standard Error of Measurement: based on Internal Reliability Coefficients,

Confidence Intervals are at 90% and 95% for each subtest and composite score.

Validity –

Intercorrelation Analyses: correlation between the subtests ranged from .45 - .67

Boston Assessment of TBI-Lifetime (Fortier, C., Amick, M., Grande, L., McGlynn S, Kenna A, Morra L, et al., 2013), is a self-report questionnaire for intake of blast injury history specifically for veterans, plus other life events that may have resulted in force to the head. It is structured in an interview format, where the veteran is asked if they experienced various types of injuries, and if so, was there loss of consciousness, or did they feel dazed or confused at the time of injury. The score then places the veteran in a mild, moderate, and severe TBI range. The mild range in separated into three grades.

Interrated reliabilities were extremely strong (all Cohen *ks* >0.80).

Validity – the validity of the BAT-L was assessed by determining the agreement between this tool and the Ohio State University TBI Identification Method (OSU-TBI-ID). The OSU-TBI-ID is the only other currently published TBI questionnaire, and it is reported to be psychometrically sound. Results revealed very strong consistency between these two tools (Cohen *k* = 0.89; Kendall τ-b = 0.95).

SCAN-3 *adult version,* for auditory processing (Keith, R. 2009).

The following information was obtained from the *SCAN-3 for Adolescents & Adults* manual. The subtests that compile the composite score include the Auditory Figure Ground 0 dB, Filtered Words, Competing Words-Direct Ear, and Competing Sentences. An supplementary subtest, Time Compressed Sentences, will also be administered. The assessment takes 20-30 minutes to complete. The assessment is presented via a CD on a laptop computer. Stereo headphones with a broad flat-frequency response between 250 and

8000 Hz are used for the subject to hear the stimuli. A Y-adapter is used so both the subject and examiner may hear the stimulus simultaneously. The laptop is positioned so the subject can not see the screen and therefore limit distractions.

Auditory Figure-Ground 0 db assesses the ability to process speech in the presence of background noise at 0 dB signal-to-noise ratio, which means the stimulus words are presented at the same volume level as the background noise. The background noise consists of a group of people speaking as in a crowded gathering. The test is normed for ages 13:0 to 50:11.

Filtered Words is used to assess the subject's ability to process distorted speech by presenting monosyllabic words low-pass filtered at 750 Hz.

Competing Words-Direct Ear assesses the ability to process competing speech signals by presenting a monosyllabic word to each ear at the same time. The subject is directed to repeat both words in a specific ear order.

Competing Sentences assesses the ability of the subject to processes competing speech signals by presenting pairs of unrelated sentences to the right and left ears. The subject is directed to repeat the sentence heard in one specific ear.

Time Compressed Sentences assesses the subjects' ability to process degraded speech by presenting sentences that have been time compressed at 60%, so the speech is at a rapid rate.

Reliability –

Test-Retest Stability: the corrected stability coefficients for the composite is (.78), Time Compressed Sentences (.75), Auditory Figure-Ground 0 dB (.68), Filtered Words (.59), Competing Words-Directed ear (.80), and Competing Sentences (.80). The scores are averaged across all ages.

Internal Consistency: The reliability coefficients of the test were computed with Fisher's z transformation and are averaged across all ages. Time Compressed Sentences (.70), Auditory Figure-Ground 0 dB (.76), Filtered Words (.91), Competing Words-Directed ear (.87), and Competing Sentences (.93), Composite (.93).

Inter-scorer Agreement: very high ranging from (.98 to .99).

Standard Error of Measurement: based on Internal Reliability Coefficients, Time Compressed Sentences (1.70), Auditory Figure Ground 0 dB (1.50), Filtered Words (0.92), Competing Words-Directed Ear (1.07), Competing Sentences (0.86), and Composite score (4.04).

Confidence Intervals are at 90% and 95% for each subtest and composite score.

Validity –

Intercorrelation Analyses: correlation between the subtests that contribute to the Composite score and the Composite score – Competing Words-Directed Ear (.83), Competing Sentences (.59), Auditory Figure Ground 0 (.67), and Filtered Words (.68).

Effect sizes for the test and composite scores were moderate to large, ranging from (.62 to 1.23), except Filtered Words (.25).

Auditory Consonant Trigrams (Stuss, D., Stethm, L., & Poirier, C., 1987; Paniak, Miller, Murphy, Andrews, & Flynn, 1997). – a trigram is a set of 3 consonant letters that do not form a word. This is done so that a subject's previous knowledge does not affect the task. The trigram has little or no meaning, so no associations can be made to facilitate one's memory systems. There are no vowels in the trigram, so as to prevent any easy pronunciations. This makes it more difficult to remember the trigram. The trigrams are all equal in length, there for the experiment is less biased by the information the subject is required to remember.

The subjects are presented with a trigram and asked to remember it. Next they are given a delay between presentation of the trigram and when asked to recall the trigram. During this delay an interference task is presented. The delay intervals consist of 3, 6, 9, 12, 15, or 18 seconds. Peterson & Peterson (1959) study found successful recall with a 3 second delay to 50% with healthy adults. This success rate decreased to 10% with delays from 6 to 12 seconds, and 5% success with delays of 18 seconds. This assessment is widely used by neuropsychologists to assess memory.

<u>Reliability</u> – Internal consistency on Cornbach's r = .85 is high.

Validity – correlation with Digit Span Backward Test was moderate (*r* = .54 - .57).

Stuss et al. (1989) reported the CCC was sensitive to differentiate patients with mild concussion.

Normed for ages 16-69 years.

Administration Time is 10 minutes.

Symbol Digit Modality Test (Smith, A., 1982) for working memory and processing speed and is utilized for Traumatic Brain Injured as well as other neurological diseases that may affect a person's cognitive abilities. The SDMT measures the time to pair abstract symbols with specific numbers.

Reliability – test-retest reliability ranges between 29 days to 2 years (r=.70 to .91) (Smith, A., 1982).

Validity - content validity (r=.78) (Smith, A., 1982). Construct validity: SDMT correlates well with the Wechler Digit Symbol subtest (r-.62 to .91) (Hinton-Bayre, et al., 1999). Administration time is less than 5 minutes.

Trail Making Test – form A & B – for attention, processing speed and mental flexibility. The *Trail Making Test* (TMT) has been widely used as an assessment tool for many years. First developed by the Army in 1938, it was validated for use in the late 1950's by Reitan and later incorporated into The Halsteid-Reitan Neuropsychological Test Battery.

The Trail-Making Test is a standardized set of two visual search and sequencing task that are heavily influenced by attention, concentration, resistance to distraction, and cognitive flexibility or set-shifting. Its primary use is for the evaluation of brain injury and other central nervous system disorders. Normative scores are provided in the form of *T* scores, which have a mean of 50 and a standard deviation of 10 with their accompanying percentile ranks. The task of test A is to connect a series of stimuli, numbers in serial order as fast as possible without lifting the pencil. Task B is the same except the subject is required to connect numbers and letters in a specified order (1A, 2B, 3C etc.) as fast as possible. The score derived for each trail is the number of seconds required to complete the task. The composite score is obtained by pooling the *T* scores from the individual trails. This test is sensitive to neuropsychological deficits. Administration time is 5-10 minutes.

Interrater reliability is .94 for task A and .90 for task B.

Validity – part A versus Part B are moderately correlated (*r* = .31- .60)

TMT is ranked as the top instrument for attention.

The adult form age range is 15-89 years.

This test is sensitive to neuropsychological deficits. It is standardized on a nationwide sample of 1664 people ages 8-74.11 years. Their demographic characteristics match the US 2000 Census data. Reliability scores for each trail and the composite scores has a reliability coefficient of .90 or higher for all ages.

Syntactical Prosodic Comprehension Sentence Task (Balasubramanian, V., 1987) – subject will be presented with 20 pairs of ambiguous sentences, which will be presented via audio cassette. Each sentence pair is identical with the only difference consisting of phrase pausing, i.e. “Let’s eat grandma.” “Let’s eat, grandma.” The subject will then be required to explain the meaning of each sentence.

Hearing Screening completed with Maico MA-39 Audiometer ANSI S3.6-1989 calibrated annually by Northeastern Technologies Group per manufacturer specifications, or the Maico MA-25e 2016.

Amendments:

Several amendments were made to this study’s methodology to increase recruitment. One was expanding the age range to 45 years of age instead of 40 years of age. Another amendment was to decrease the minimal amount of blast exposure from two blasts to a single blast. The final amendment was to expand the locations of recruitment from VA health clinics to other VA organizations, universities, and social media sites.

Chapter IV

RESULTS

Twelve subjects were recruited for the bTBI experimental group and six subjects were recruited for the control group. Since the required amount of subjects (N = 32) needed to reach power for an independent *t*-test a Post Hoc was run.

Post Hoc for simulation of power was run for a Mann-Whitney U Test. Mann-Whitney U Test is a non-parametric test equivalent to an independent *t*-test, but will accommodate the small sample size. Even so, notice with the small sample size the power is low, suggesting a high chance for type II errors, where the null hypothesis may be accepted when in fact the alternate hypothesis would have been true.

Figure 5. Post Hoc for an exact test

$n1 = 12$; $n2 = 6$; $df = 5$; delta = 1; $a = 0.05$; n simulation = 1000, P=0.3238

Note: Post Hoc was run with statistical program *G-Power.* Power set at .80 was not reached.

R version 3.3.1 (2016-06-21) statistical program was used to calculate all following statistics.

Table 1

Demographic and clinical data relevant to the bTBI and control groups

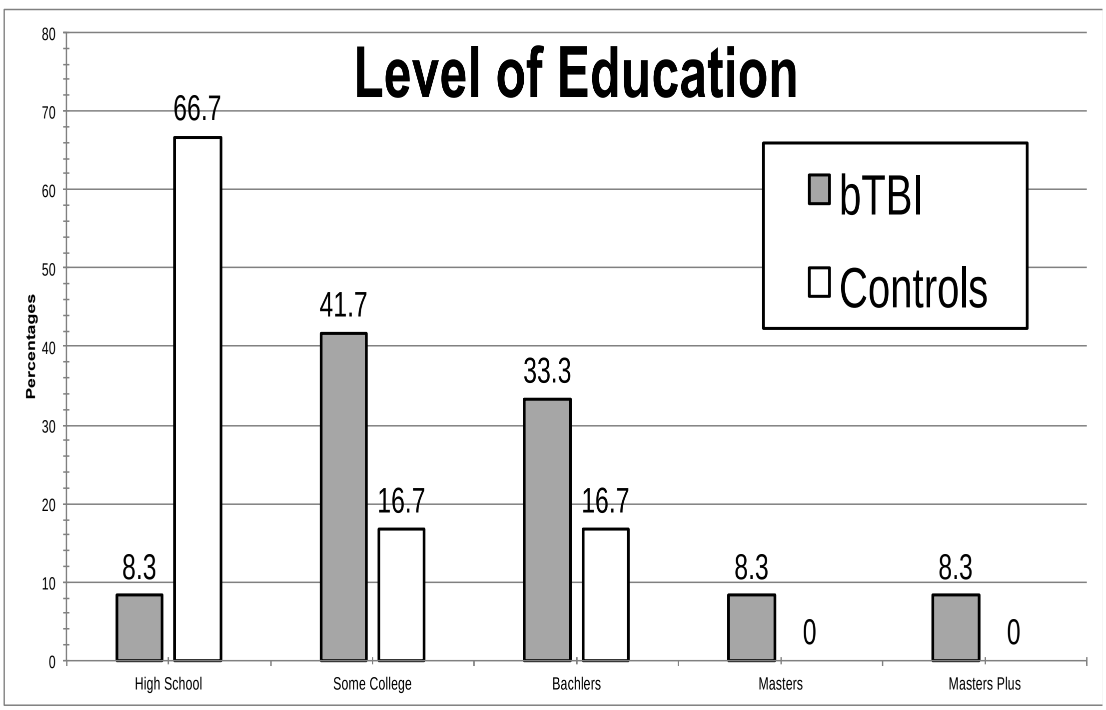
Subject	Branch	Age	Race	Education	Gender	PTSD
bTBI						
1	Army	31	Caucasian	14	Male	Yes
2	Marines	38	Black	18	Male	Yes
3	Navy	31	Caucasian	14	Male	Yes
4	Marines	26	Hispanic	14	Male	Yes
5	National Guard	33	Black	16	Female	Yes
6	Army	43	Caucasian	12	Male	Yes
7	Army	34	Caucasian	14	Male	Yes
8	Navy	44	Caucasian	14	Male	Yes
9	Army	24	Caucasian	14	Male	No
10	Army	33	Caucasian	16	Female	Yes
11	Marines	44	Hispanic	20	Male	No
12	Army	44	Caucasian	16	Male	No
Controls						
13	Navy	34	Caucasian	12	Male	No
14	Army	41	Caucasian	12	Male	Yes
15	Navy	21	Caucasian	12	Female	No
16	Marine	21	Caucasian	12	Male	No
17	Airforce	36	Caucasian	17	Male	No
18	Navy	40	Caucasian	14	Male	No

Note: bTBI Age *M* = 35.41 years, *SD* = 7.11 years; Years of education *M* =15.16 years, *SD* = 2.29 years
Control Age *M* = 32.16 years, *SD* = 9.02; Years of education *M* = 13.16 years, *SD* = 2.04 years

Table 1 reveals the demographics of the subjects. In the bTBI group six (50.0%) were enlisted in the Army, three (25.0%) were enlisted in the Marines, two (16.6%) were enlisted in the Navy, and 8.3% were enlisted

National Guard. In the control group 50% were enlisted in the Navy, and 16.7% were enlisted in each the Airforce, Army, and Marines. Gender were ten (83%) male and two female (17%) in both the bTBI group, and the control group. The prevalence of PTSD in the bTBI group was 75% (9 subjects), and the control group the prevalence was 17% (1 subject).

Figure 6. Highest Level of Education Controls and Experimental Groups



Note: bTBI Years of education *M* =15.16 years, *SD* = 2.29 years; Control Years of education *M* = 13.16 years, *SD* = 2.04 years

Table 2
Demographic and clinical data relevant to the bTBI

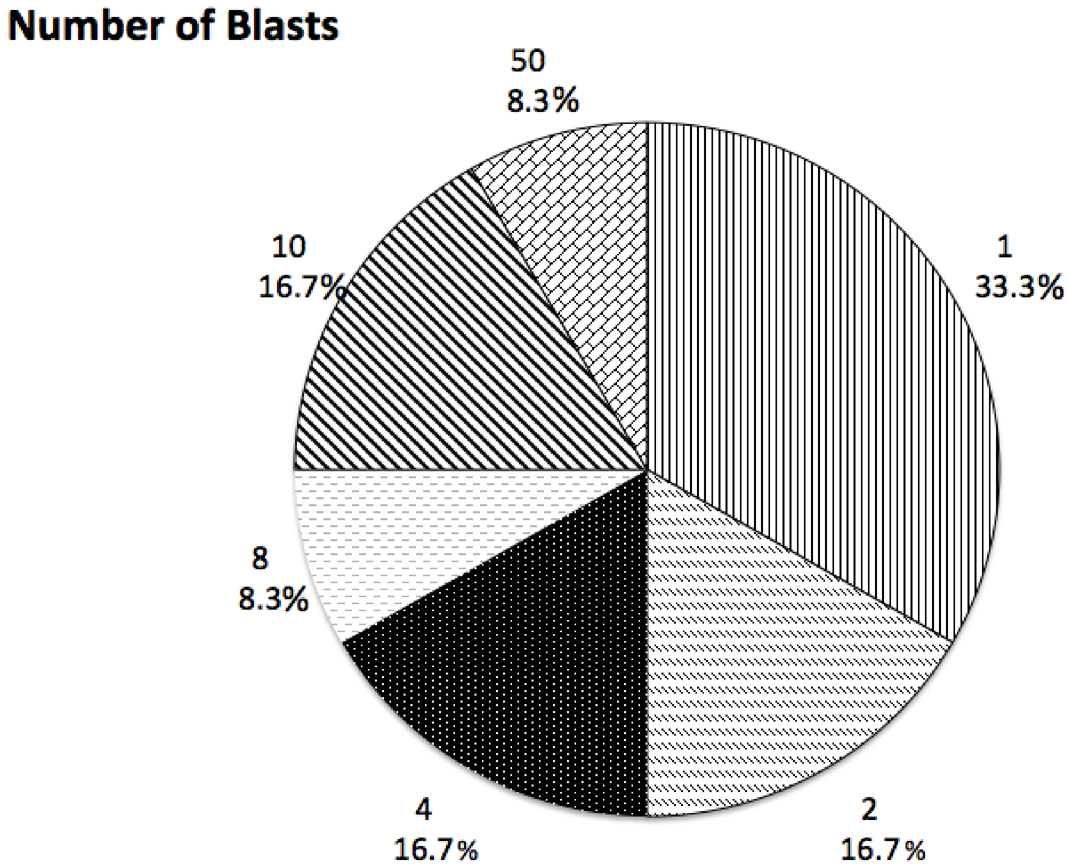
Subject	**Blast Type**	**Blast Total**	**Blast Severity**	**Distance (meters)**	**Years (post last blast)**
1	Primary	2	mod/grade II	67;74	2
2	Tertiary	1	mild/grade II	50	11
3	Primary	4	mild/grade I	10;25;40	3
4	Primary	1	mild/grade II	< 15	7
5	Quantranary	1	mild/grade I	< 10	4
6	Primary	4	mild/grade II	11;26;26	10
7	Primary	1	mild/grade II	50	6
8	Primary	8	mild/grade II	5;11;11	14
9	Primary	50	mild/grade I	< 10; 10;10	2
10	Primary	2	mild/grade I	< 10;< 25	14
11	Primary	10	mild/grade I	< 10;< 25;< 100	6
12	Primary	10	mild/grade I	< 10;<25;<25	25

Note: Blast total *M* = 7.83, *SD* = 13.72; Blast Severity M = 1.75, *SD* = 1.13; Distance from Blast *M* = 26.57, *SD* = 24.69; Years post onset *M* = 8.66, *SD* = 6.67.
Bolded subjects were not wearing their helmet on at least one blast exposure.

Table 2 demonstrates the type and severity of the blast exposure each bTBI subject experienced. The number of blast exposure ranged from 1-50 blasts with an average of 7.83 blasts and the standard deviation of 13.72 blasts. Primary blast exposure was the most frequent type of blast experienced by these veterans (83%) with one (8.3%) veteran experiencing a tertiary blast, and one (8.3%) veteran experiencing a quantranary blast effect. Six (50%) of the veterans experienced a mild grade I blast exposure, four (41.7%) experienced a mild grade II blast exposure, and one (8.3%)

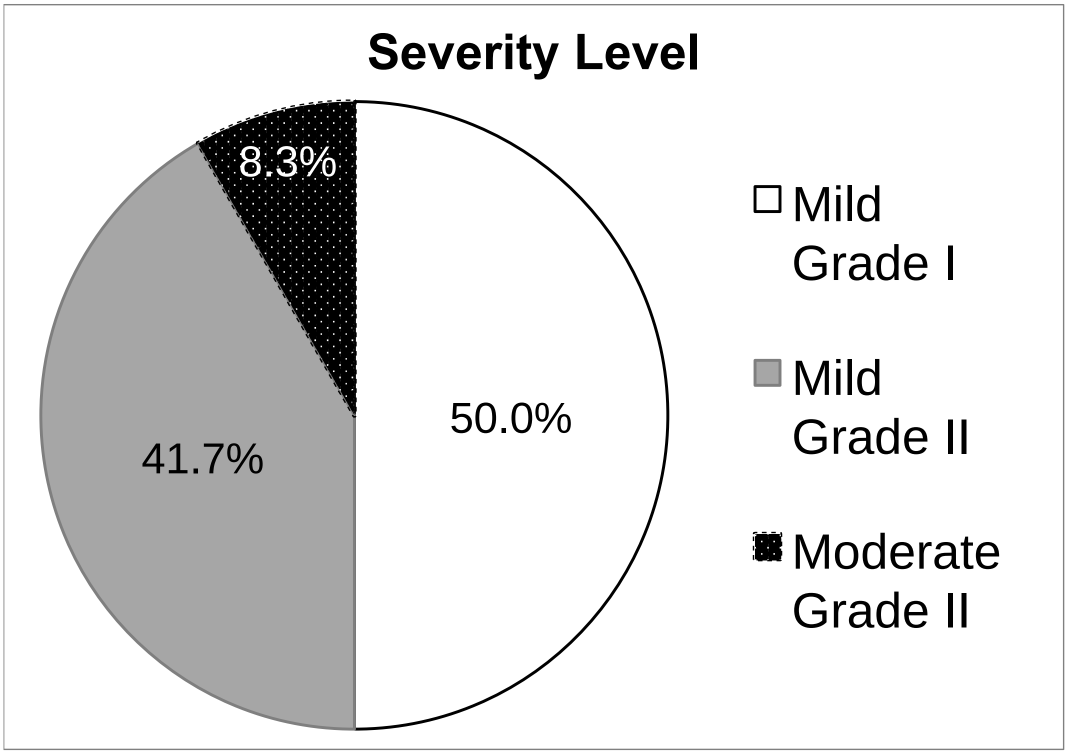
experienced a moderate grade II exposure. Distance, in meters, the veteran was from the blast ranged from 5 meters to less than 100 meters. The average distance a veteran was from the point of blast was approximately 26.57 meters. Years since the subjects' last blast exposure at time of testing ranged from 2-25 years with an average of 8.66 years. An unexpected finding was that 41.6% of the bTBI subjects were not wearing their Kevlar upgraded helmet at the time of at least one blast exposure. These subjects are identified by the bolded numerals.

Figure 7. Total Number of Blast Exposures per Subject



Note: Blast total *M* = 7.83, *SD* = 13.72.

Figure 8. Severity Score of Blast Exposure



Note: Blast Severity M = 1.75, *SD* = 1.13, as per *Boston Assessment of TBI-Lifelong*

Table 3

Results of a Mann Whitney U for Each Outcome Measure. bTBI and Control.

Assessments	Sub-test	Sig (1-tailed)	bTBI mean (SD)	Control mean (SD)
Cognitive assessments				
	ACT-3	0.197	86.33 (14.32)	96.50 (3.83)
	ACT-9	0.704	74.16 (21.36)	81.50 (16.07)
	ACT-18	0.254	69.83 (24.44)	82.60 (15.59)
	TMT-A	*0.044	29.11 (8.94)	20.27 (6.20)
	TMT-B	*0.001	57.08 (22.25)	53.28 (24.84)
	SDMT	0.963	51.66 (9.25)	52.50 (14.19)
Auditory Processing				
SCAN-3	Total	0.348	94.16 (16.30)	100.16 (10.81)
	AFG	0.598	9.50 (1.88)	9.00 (2.36)
	FW	0.075	9.91 (1.92)	11.50 (1.37)
	CW-DE	0.571	8.66 (3.60)	9.66 (3.32)
	CS	0.335	8.91 (2.60)	10.33 (24.03)
	TCS	*0.028	10.08 (1.78)	12.00 (0.00)
Higher-level Language				
CASL	Sent. Comp.	0.279	85.58 (13.55)	90.50 (20.81)
CELF-5 Meta	MSI	0.187	95.58 (9.71)	101.50 (10.19)
	Inf	0.538	10.66 (2.30)	11.66 (2.65)
	MM	0.184	9.75 (2.13)	10.50 (2.25)
	Fig lang.	0.195	8.83 (2.30)	10.16 (1.86)
Prosodic Comp Test		0.272	65.0 (0.20)	76.66 (0.12)
Blast Injury Severity				
	BAT-L		5.66 (0.21)	N/A

Note: ACT = *Auditory Consonant Trigrams*; TMT = *Trail Making Test*; SDMT = *Symbol Digit Modality Test*; AFG = Auditory Figure Ground; FW = Filtered Words; CW-DE = Competing Words-Directed Ear; CS = Competing Sentences; TCS = Time Compressed Sentences; CASL = *Comprehensive Assessment of Spoken Language;* Sent. Comp. = Sentence Comprehension; CELF-5 Meta = *Clinical Evaluation of Language Functioning-5 Metalinguistic;* MSI = Metalinguistic Semantic Index; Inf = Inferencing; MM = Multiple Meanings; Fig. Lang. = Figurative Language; BAT-L = *Boston Assessment of TBI-Lifetime.* *$p \leq 0.05$.

Table 3 presents the statistical results of the difference of two independent samples (bTBI veterans/no blast veterans). Only three areas reached significance: *Trail Making Test-A* (p = 0.044), *Trail Making Test-B* (p = 0.001), and a subtest from the SCAN-3, Time Compressed Sentences (p = 0.028). In general a trend is noted on all subtests, with the exception of the Auditory Figure Ground subtest of the SCAN-3, that the bTBI group performed poorer that the control group.

Table 4

Results of the Mann Whitney U for each outcome measure. Helmet and No Helmet.

Assessments	Sub-test	Sig (1-tailed)	Helmet mean (SD)	No Helmet mean (SD)
Cognitive assessments				
	ACT-3	0.59	89.00 (10.34)	82.60 (19.33)
	ACT-9	0.51	76.85 (15.28)	67.00 (28.18)
	ACT-18	0.86	73.14 (17.63)	65.20 (33.62)
	TMT-A	0.32	25.26 (2.89)	34.09 (12.5)
	TMT-B	0.19	54.24 (20.51)	61.07 (15.22)
	SDMT	0.32	30.47 (12.46)	40.29 (4.72)
Auditory Processing				
SCAN-3	Total	0.10	101.42 (16.93)	84.00 (8.88)
	AFG	*0.05	10.28 (1.60)	8.40 (1.81)
	FW	0.23	10.57 (2.22)	9.00 (1.0)
	CW-DE	0.08	10.29 (3.72)	6.40 (1.94)
	CS	0.21	7.71 (2.42)	7.80 (2.68)
	TCS	1.00	10.14 (1.86)	10.00 (1.87)
Higher-level Language				
CASL	Sent. Comp.	0.13	89.14 (9.42)	80.60 (17.85)
CELF-5 Meta	MSI	0.08	99.42 (8.67)	90.20 (9.20)
	Inf	*0.04	11.85 (1.77)	9.00 (2.00)
	MM	0.08	10.71 (0.95)	8.4 (2.70)
	Fig Lang.	0.50	9.28 (2.28)	8.20 (1.64)
Prosodic Comp Test		0.31	72.85 (0.17)	54.0 (0.21)
Blast Injury Severity				
	BAT-L	0.85	5.50 (5.85)	5.20 (4.43)
Number of Blast Exposures		0.40	10.42 (17.69)	4.20 (4.43)

Note: ACT = *Auditory Consonant Trigrams*; TMT = *Trail Making Test*; SDMT = *Symbol Digit Modality Test*; AFG = Auditory Figure Ground; FW = Filtered Words; CW-DE = Competing Words-Directed Ear; CS = Competing Sentences; TCS = Time Compressed Sentences; CASL = *Comprehensive Assessment of Spoken Language;* Sent. Comp. = Sentence Comprehension; CELF-5 Meta = *Clinical Evaluation of Language Functioning-5 Metalinguistic;* MSI = Metalinguistic Semantic Index; Inf = Inferencing; MM = Multiple Meanings; Fig. Lang. = Figurative Language; BAT-L = *Boston Assessment of TBI-Lifetime.* $^*p \leq 0.05$.

Table 4 shows two areas of significance that was revealed when comparing the bTBI veterans who had been wearing their updated helmets to those bTBI veterans who were not wearing helmets when exposed to at least one of their blasts. One of the two areas was auditory figure ground, p = .05, and inferencing, p = 0.04. There were also three areas that demonstrated a trend: competing words-directed ears p = *0.08;* multiple meanings p = 0.08; and metalinguistic semantic index p = 0.08. The metalinguistic semantic index is a combination of the multiple meaning and figurative language subtests.

Table 5

Results of Spearman Rho for bTBI combined group and bTBI No Helmet group

Assessments	Auditory Processing				Higher-Level Language	
Cognitive Ass.	Fig. Ground		TCS		Inferencing	
	bTBI	No Helmet	bTBI	No Helmet	bTBI	No Helmet
ACT-3	0.33	0.05	-0.02	-0.80	0.30	0.54
ACT-9	0.41	0.30	-0.10	-0.73	0.21	0.66
ACT-18	0.14	-0.28	-0.07	-0.72	0.14	0.28
TMT-A	-0.11	0.35	-0.14	0.26	-0.24	-0.05
TMT-B	-0.16	-0.35	-0.34	-0.15	-0.34	-0.35
SDMT	0.05	-0.15	-0.33	-0.26	0.26	0.20
Auditory Processing						
FG	-	-	0.25	-0.13	0.54	0.81
TCS	0.25	-0.13	-	-	-0.15	-0.64
Number of Blasts	0.38	0.34	0.21	0.17	0.46	0.28
BAT-L	0.03	0.59	0.10	0.30	-0.19	0.14

Note: ACT = *Auditory Consonant Trigrams*; TMT = *Trail Making Test*; SDMT = *Symbol Digit Modality Test*; AFG = Auditory Figure Ground; TCS = Time Compressed Sentences; BAT-L = *Boston Assessment of TBI-Lifetime*

Table 5 demonstrates correlations with areas that reached statistical significance: figure ground, time compressed sentences, inferencing, and cognitive assessments (*Auditory Consonant Trigrams, Trail Making Tests, and Symbol Digit Modality Test*). There are several areas that demonstrate a correlation for the subjects who were not wearing a helmet when exposed to a blast: a strong correlation was revealed between *Auditory Consonant Trigrams 3, 9, 18,* and Time Compressed Sentences (r = -0.80, -0.73, -0.72, respectively); Inferencing and Auditory Figure ground (r = 0.81); a moderate correlation was revealed between bTBI with no helmet and *Auditory Consonant Trigrams 3*, and *9* and Inferencing (*r* = 0.54 and 0.66 respectively), and Auditory Figure ground and Time Compressed Sentences (*r* = -0.64). Finally, there was a moderate correlation between bTBI with no helmet *Boston Assessment of TBI-Lifetime* and Auditory Figure Ground (*r* = 0.59). For the bTBI experimental group only one are of correlation was noted, which was a moderate correlation between auditory figure ground and inferencing (*z* = 0.54).

Chapter V

DISCUSSION

The aim of the present study was to investigate the factors that may have a negative impact on the reintegration into civilian life of serviceman who were exposed to blasts. The hypothesis was that blast exposed veterans would not perform as well as non-blast exposed veterans on tasks of higher-level language (inferencing, ambiguity, figurative language, and complex syntactical structure comprehension), tasks and auditory processing tasks. It was also hypothesized that these tasks may be correlated with cognitive functions of memory, attention, and visual processing speed, number, or blast exposures and severity level of blasts.

There are three main areas to address in the discussion, higher-level language, auditory processing, and neurocognitive results with the bTBI, and the bTBI group that was without head protection. During the interview portion of the assessment with the *BAT-L* it was revealed that five of the twelve bTBI subjects were for various reasons not wearing their upgraded helmet at the time of the blast exposure. This led to further analysis. First we will discuss the bTBI as a whole group and then separate the experimental group into those who were wearing their upgraded helmet and those who were not.

Higher-Level Language

The results from this study differ from the results from Barwood and Murdoch (2013). Their study found significance between the mTBI and controls with inferencing, ambiguity, and figurative language. However, results were consistent with the subtest inferencing *(p* = 0.04) with the veterans that were not wearing their upgraded helmet at the time of explosion. There was also a weakness for multiple meaning words and figurative language with unprotected vets. Barwood and Murdoch demonstrated a significance with ambiguity (multiple meaning) and figurative language subtests. This difference may be due to the lack of subjects in this present study, which increased the probability of type II errors, suggesting that the null hypothesis was excepted when in fact a significance may have been present. Barwood and Murdoch recruited sixteen subjects for each the control and experimental group.

Though no other trends, or significance was reach the control group performed better on all higher-level language tasks than the bTBI group, and the helmeted bTBI group performed better on all these higher-level language tasks than the bTBI group, who were without an upgraded helmet at the time of exposure.

Surprisingly this studied did not show significance with syntactic comprehension, or complex sentence comprehension. Research by Wilson & Wharton, 2005; Fry, 1958; and Rodero, 2015 all demonstrated the need for increased attention for the comprehension of syntactic prosody. This study's subjects, though demonstrating decreased attention, did not demonstrate weaknesses in syntactic prosodic comprehension. This may be secondary to the design of the task. There was no time limit on these tasks, and the stimulus was allowed to be repeated at the subjects request, therefore removing the element of real time words (120 to 180 per minute), and decreasing the demand.

These finding provide evidence that veterans exposed to blasts who did not have head protection are at risk for decreased listening comprehension and difficulty using content and context to make situationally appropriate inferences. Weaknesses with their ability to process and understand language with multiple meanings and abstract idiomatic expressions was also noted. The bTBI's performance on these standardized tests suggests problems with complex language comprehension.

Auditory Processing

Another area of interest is the significance level reached with in the spectrum of auditory processing deficits. The bTBI group reached significance (p = 0.04) on the *SCAN-3* subtest- Time Compressed Sentences, which suggests there is difficulty when an extra demand of listening and processing quickly is applied to the subjects auditory system. This subtest is a low-redundancy speech tasks, specifically an auditory closure task. Poor performance on this task may indicate that the subject will have decreased functional capabilities for processing rapid changes in acoustic stimuli noise (Welling and Ukstins, 2015).

Auditory Figure ground, also a low-redundancy speech task, reached significance (*p = 0.053*) with the bTBI subjects that were without helmets. Again suggesting the blast exposure weaken the auditory processing system and back ground noise adds extra strain to the processing system. Those who perform poorly on these two subtests may miss pieces of auditory information when the information is distorted in some way, as with rapid rate of delivery or presented in the presence of background noise (Welling and Ukstins, 2015). This would be consistent with research and with the veteran's complaints of passing their hearing tests but having difficulty understanding what they hear (Lew, Jerger, Guillory and Henry, 2007).

Significance on figure ground and time compressed sentences is supported by Saunders, Frederick, Arnold, Silverman, Chisolm, and Myers' (2018) study, who also reported that these two auditory processing subtests were most often affected by blast exposure in the ninety nine subjects they evaluated.

Literature is not consistent with this study's findings. Gallun, Diedesch, et al. (2012) assessed 36 veterans one year post exposure to a blast. A control group of 29 subjects had no history of blast exposure. The control group was matched by age and hearing acuity. Hearing loss was allowed up to 50 dB.

Three auditory processing tests, which demonstrated large effects for blast exposed subjects were: Gaps-In-Noise task, which looks at auditory temporal resolution, The Masking Level Difference task, which looks at binaural processing and sound localization, and the Staggered Spondaic Words test, which is a dichotic test. These tests are consistent with damage to the cortex and corpus callosum. Damage to the temporal lobe and corpus callosum is consistent with blast literature. A limitation to this study was the allowance of a hearing loss, which could have biased the findings of APD. Of the five top audiological diagnoses reported among veterans, auditory processing disorders were ranked number five (Roth, 2012). The difference between the two studies may be that the Gallun et al. study had more subjects, or that the Gallun et al. study allowed for hearing loss up to 50 dB. The present study required subjects to pass a hearing screening set at 25dB. All but one subject passed the hearing screening. The one subject that did not pass presented with reduced hearing acuity in the right ear only (1K Hz passed 35 dB, and 2K Hz passed at 30 dB), and it was judged that the pattern of difficulty was not consistent with a pattern negatively influenced by a unilateral hearing loss. Therefore, he was not excluded from the study.

Though no other trends, or significance was reach the control group performed better on all auditory processing tasks than the bTBI group. And except for the Competing Sentences and the Time Compressed Sentences subtests the helmeted bTBI group performed better on all of these auditory processing tasks than the bTBI group, who were without an upgraded helmet. The finding of the present study supports the possibility of underlying neurological disorganization, or damage to auditory pathways, or corpus callosum. Functionally, it would cause difficulty with auditory comprehension in noisy situations, and increased demand on the auditory memory system.

Neurocognition

Finally, this study found significance in the cognitive arena on a test of processing speed and attention, the *Trail Making Test A&B* (p = 0.04 & p = 0.001). This has been recorded in the literature as being consistent with the diagnosis of mild TBI (Thaler, 2013), which would provide evidence that blast exposure does mimic mild head injuries. Some of the symptoms reported in the literature were memory loss, attention and concentration difficulties, slowed thinking, and confusion (Drake, 2010; Kennedy, Cullen, Amador, Huey, & Leal, 2010), plus speed of processing and executive functions (Cornis-Pop et al., 2012). The Veterans Affairs/Department of Defense (2009) list the following neurocognitive areas the bTBI population may exhibit deficits in: attention, concentration, memory, speed of processing, judgment, and executive function. There was no significant differences on these neurocognitive tasks when comparing the veterans who were wearing an upgraded helmet with those veterans who were without a helmet. Suggesting that either the attention weakness is secondary to PTSD, or that the upgraded helmets are not able to protect the Frontal Lobe, which is responsible for attention.

Baddeley (2003) reports how memory and attention are needed to comprehend complex sentence structures. Comprehension depends upon the ability to retain the beginning of a sentence to accurately interpret the whole meaning. The limited capacity theory of working memory states that the phonological loop or verbal working memory, which is made up of storage and processing function, share the same limited amount of cognitive resources. The processing portion is responsible for the language operations, such as lexical, morphological, grammatical, and/or propositional functions. The storage portion is responsible for temporarily retaining verbal information that has been processed. If the processing portion is weak, then the individual may need to give more energy to processing difficult information and then they may forget some of the information they heard. If the storage portion is limited then they will use more energy to store the data and have less to process new information (Hay & Moran, 2005). Given this information one would have expected the bTBI population to have had more difficulty on the *CASL* subtest Sentence Comprehension, which required the subject to comprehend if two syntactically complexed sentences meant the same thing or not (i.e. “ One of the pictures on the dresser is of my dog.” “My dog’s picture is one of the pictures on the dresser.”). Though these subjects did not demonstrate significance, nor a trend on this subtest this may be due to the allowance of the stimuli to be repeated and the absence of a time constraint. Had the format of this task placed higher demands on the working memory capacity, or attention component as with the *SCAN-3* subtest of time compressed sentences a trend may have been revealed? Future research on this area is needed.

Though no other trends, or significance was reach the control group performed better on all of the neurocognitive tasks than the bTBI group. And except for the *Symbol Digit Modality Test* the helmeted bTBI group performed better on all of these neurocognitive tasks than the bTBI group who were without an upgraded helmet. Findings on these standardized assessments provide evidence of difficulty associated with tasks that require frontal lobe support. Frontal lobe deficits is common place with mTBI subjects.

Relationships

There were several correlations revealed. The stronger correlations were with the veterans who were not wearing their helmets with memory and repetition of rapid speech samples; and comprehension in the presence of back ground noise with inferencing. Moderate correlations were again with the veterans who were not wearing their helmets with inferencing and memory, inferencing with repetition of rapid speech, and comprehension of words in the presence of background noise with the severity level of the blast. Degeneration in auditory performance is what is being reported years post exposure to acoustic trauma (Fausti, et al., 2009, Kujawa & Liberman, 2009). This may be the foundation to this relationship.

There was only one area that demonstrated a correlation for the whole bTBI group, and that was in the area of comprehension of words in the presence of back ground noise with inferencing.

Hartley, (1995); Sohlberg, (2009); and Sohlberg and Mateer, (2001) (as cited in Cornis-Pop et al., 2012) reported numerous communication skills that may be impaired due to cognitive changes in mTBI. The cognitive changes include attention deficits, which may cause difficulty with learning new information, difficulty conversing when there is background noise, or distractions, difficulty when reading complex or lengthy material, difficulty shifting or maintaining a topic. Speed of processing may delay responses during conversation, or make it difficult to comprehend rapid rate of speech, maintain a topic, or cause an increase in pause time during conversations. Memory deficits may cause difficulty in recalling instructions or messages, difficulty in learning new information, remembering names, recalling details, maintaining a topic, repetition tasks, cause lack of coherence in conversation, or comprehending abstract language. This current study substantiates Hartley, Sohlberg, and Sohlberg and Mateer study's findings.

Interference with one's sustained attention during instructions, or a conversation will interfere with comprehension. The interruption of attention may result in missed information, or an inflection change, which changes the meaning of the message, therefore impeding comprehension (Cornis-Pop et al. 2012, Kristensen, Wang, Petersson, & Hagoort, 2013). The findings in this current study did support Cornis-Pop et al. and Kristensen et al. hypothesis.

Tun, Williams, Small, & Hafter, (2012) completed a literature review on the effects of aging on auditory processing and cognition. These authors report how speech places a significant weight on attention and working memory, because in real time words are spoken at a rapid rate of 120 to 180 words per minute. This places tremendous stress on attention and memory because the listener cannot go back to re-play the speakers words, the listener must attend to the speech signals so as to encode the auditory signals, access lexical items, syntax, and semantic operations, all while holding onto previous information in the memory system. Declines in these areas are correlated to subjects increased difficulty with listening with background noise, which then may lead to the decline in quality of life activities, such as giving up social activities. Our subjects' difficulty on the *Trail Making Test AB* demonstrate a weakness with attention and processing speed. Based on the literature one of the factors is possibility that the weakness in attention precipitated the weakness in auditory figure ground, time compressed sentences and inferencing. Again these findings support frontal lobe involvement, typical of mTBI subjects.

Chapter VI

SUMMARY AND CONCLUSIONS

This study has provided new insights into other issues and concerns impacting Gulf War Veterans. The results from this current study would suggest that there are areas of auditory processing and higher-level language that are effected by blast exposure, more specifically, auditory figure ground, time compressed sentences and inferencing. For the most part these effects are minimized by the use of the upgraded helmets issued to the soldiers, demonstrating the effectiveness of the protective gear and the importance of wearing the helmet at all times. Results would suggest that veterans who have been exposed to blasts should have a complete audiological evaluation including auditory processing testing, especially if they complain of hearing difficulties in the absence of a pure-tone hearing loss. In addition, veterans who have had blast exposure should have a complete speech/language evaluation, which should include evaluation of higher-level language skills of inferencing, ambiguity, and figurative language. Finally, the use of the BAT-L includes pertinent questions such as “were you wearing your Kevlar gear and upgraded helmet?” Utilizing this formalized interview format will identify those veterans at higher risk for the deficits noted in this study.

The findings of this present study provide evidence that veterans who sustained blast exposure, especially those who were not wearing helmets at time of the exposure may have difficulty integrating information to make appropriate inferences and draw logical conclusions, difficulty listening in noisy environments, comprehending rapid speech, understand ambiguous statements, and accurately interpret figurative language. These limitations may interfere with blast exposed veterans ability to function successfully in their vocational, educational, and social settings and ultimately negatively impact on their quality of life.

Limitations

Several limitations were identified in this study. First, the subjects in this study volunteered and therefore there is the potential bias of self-selection. This is the bias of not knowing what attributes are present in the volunteers, as compared to those who do not volunteer. These attributes may affect the generalizability (Portney & Watkins, 2009).

Another limitation is the low power achieved in this study (0.38). The sample size needed to obtain a sufficient power size (0.80) was 32 subjects (Portney & Watkins, 2009). This study was only successful for recruiting 18 subjects, and therefore increasing the chance of a type II error, which means there is a 68% chance that this study is failing to recognize a significance.

That there is indeed a difference between the control and experimental groups, but this study was not robust enough to demonstrate such.

There were also a few areas of the study design that decrease the strength of the study. For one the examiner was not blinded to whether or not the subject had been exposed to a blast. This was the original design, but since the examiner was the same person scheduling it became impractical to be blinded. For the subjects were asked inclusion/exclusion questions prior to being scheduled, and the amount of subjects volunteering was so limited it was obvious which subject was being tested each time. Another weakness was that testing was completed in a quiet setting, but not a sound treated room. This may have affected the results on the auditory processing testing, but all subjects were tested the same and therefore the continuity of the testing format should have controlled for itself.

Individual differences may also have played a role. Every TBI has unique pattern of presentation and sequelae: Where they were at the time of blast, in a vehicle or near a wall would cause the blast wave to rebound causing additional exposure? Which direction the blast came from, the severity of the blast, the closeness to the blast, and how many exposures? This group of bTBI averaged 7.8 blasts, quite less that the average of 14 (Fortier et al. 2014), reported in the literature. In addition, each person's background, intellectual strengths and weakness, neurological disposition vary. This all limits the studies generalizability.

Lack of normalcy within the subject groups adds another bias. The control group was less educated as a whole that the experimental group (college education 33% vs 91%). This may suggest that the experimental group has learned to compensate for their weaknesses from blast exposure, thus scoring better than another vet that has not pursued higher education. It may also suggest that the experimental group is more motivated, or presents with a higher self-esteem. This may also have strengthen their performance on the assessments. The groups also differed in the branch of service they served in. The controls were mostly Navy serviceman (50%) whereas the experimental group were mostly Army serviceman (58.3%). This would most likely represent the fact that more veterans in the Army would be exposed to blasts than the Navy, which is consistent with the literature (DoD, 2009). Lastly, there were half the amount of control subjects (6) than the experimental subjects (12), which also limited the strength of this study. Equal number of control subjects would have provided more robust results. Most of the bTBI group presented with PTSD (75%), were only 17% of the control group was effected. PTSD subjects are known for decreased focus and attention. This may have influenced these results.

Finally, educational, medical and military information was via self-report. No medical records were available to substantiate. This may have biased the study as the subjects may not have known all the details of their exposure, and/or may not have been willing to share all their pertinent data. One subject in each group reported having been diagnosed with dyslexia in elementary school. Neither were classified special education when they graduated high school.

Future research

To improve this study's strength, it should be repeat with 16 subjects in each group to obtain the statistically recommended power of 80%. It would also be suggested to recruit subjects who had more than a single blast, so as to align with the average veterans' exposure of 15 blasts. To be able to collaborate with the Department of Defense, or Veterans Hospital would improve recruitment ability.

Other areas to examine need are to look deeper into the comprehension of rapid speech in different situations, treatment studies for higher-level language weaknesses, counseling for auditory processing deficits and the effectiveness of such, family counseling effectiveness for auditory processing deficits, and higher-level language weaknesses, and educating of academic educators. Since so many veterans are returning to college after they have served, and many colleges and universities have counselors and advisors, as well as course sections just for the veterans, it may be beneficial for these staff members to be educated on the negative impact auditory processing deficits and higher-level language weakness may have on learning, and what modifications can be made to facilitate learning for these serviceman.

Finally, this research study revealed a high percentage of bTBI to present with a right ear advantage on the auditory processing assessments (75%), compared to sixteen percent (16%) of the controls. An auditory message is sent through the auditory pathway to the temporal lobes. The information received from the left ear travels to the right hemisphere and the information received from the right ear goes to the left hemisphere. Since auditory information is processed in the left temporal lobe, all information transferred to the right temporal lobe (via the left ear) must travel to the left hemisphere via the corpus callosum. By the age of eleven years any ear advantage should have disappeared and auditory information from both ears should arrive in the left temporal lobe at the same. An ear advantage means that the one side of the auditory pathway is more efficient that the other side. Right Ear Advantage would suggest that there is a weakness in the central auditory nervous system, possibly in the corpus callosum. Damage to the corpus callosum from blast exposure has been reported in the literature (Cecil, et al., 1998, De La Plata, et al., 2007, Bigler, 2008; Zhang, et al., 2006). The presence of an ear advantage in servicemen needs to be explored further.

Our servicemen and women are facing challenges with reintegration into civilian life as noted by the high levels of homelessness, unemployment, and suicide. Behavioral aspects and PTSD have been the focus of these problems, but we need to dig deeper and consider other areas of concern. There may be additional factors that negatively impact successful reintegration. This study offers an important step for veteran health, because it has revealed other areas that may be factors in the challenges veterans face with civilian life. There may be weaknesses in communication skills such as auditory processing deficits and higher-level language deficits secondary to blast exposure. Our military have sacrificed much for freedom. The least we can do as medical professionals is to provide a comprehensive assessment when behavioral issues are noted following blast exposure. This research suggests that speech-language pathologists and audiologists should be a part of the diagnostic team, so they can rule out the possibility of auditory processing, or higher-level language disorders. Much more research is needed to drill down to the causal component of the behavioral problems associated with our returning veterans, but this research is one step closer to a more successful recovery process.

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APPENDICES

Appendix A

IRB EXPEDITED REVIEW APPROVAL

Hackensack Meridian *Health*

To: Judith Koebli

CC: Venu Balasubramanian

Re: Study# Pro2016-0065
Study Protocol: The Exploration of High Level Language Comprehension Deficits and the Factors Influencing Them Following Blast Exposure in Afghanistan and Iraqi War Veterans

Study Expiration Date: 9/6/2017

This is to advise you that the above Study has been presented to the Institutional Review Board for expedited review.

Please be reminded that all modifications to approved projects must be reviewed and approved by the Institutional Review Board before they may be implemented. Any changes to this protocol must be submitted for IRB approval before initiated.

All serious adverse events and unexpected adverse events must be reported to Institutional Review Board within seven days.

Please do not make any changes to the IRB approved consent without approval of the IRB. Only the IRB stamped approved consent should be used.

If your study meets the definition of a qualifying study that meets the FDAAA 801 definition of an "applicable clinical trial", you are responsible for ensuring that the trial has been registered properly on the Clinical Trials.gov website prior to the enrollment of any subject.

"Applicable clinical trials" generally include controlled clinical investigations, other than phase 1 clinical investigations (with one or more arms) of FDA-regulated drugs, biological products, or devices, that meet one of the following conditions:

The trial has one or more sites in the United States

The trial is conducted under an FDA investigational new drug application or investigational device exemption

The trial involves a drug, biologic, or device that is manufactured in the United States or its territories and is exported for research

For complete statutory definitions and more information on the meaning of "applicable clinical trial," see Elaboration of Definitions of Responsible Party and Applicable Clinical Trial (PDF).

The revisions have been reviewed and approved via expedited review on 9/21/2016.

HIPAA Authorization is required.

Appendix B

Hackensack IRB Notification of Approval

Hackensack Meridian *Health*

NOTIFICATION OF APPROVED CONTINUING REVIEW

From:	Robert Krugman, MD
To:	Judith Koebli
CC:	Name Venu Balasubramanian
Re:	Continuing Review # CR00003802 for Study#: Pro2016-0065 Study TItle: 2017 Review for Pro2016-0065 Meeting Date: 8/2/2017 Expiration Date: 8/1/2018

This is to advise you that your application for Continuing Review for the above referenced Study has been reviewed and approved by the HUMC Institutional Review Board.

Please be reminded that all modifications to approved projects must be reviewed and approved by the Institutional Review Board before they may be implemented except to remove apparant immediate hazards to research participants.

All unanticipated problems that meet the criteria for reporting (see HUMC HRPP Policies & Procedures Sec 14.1) must be reported to the Institutional Review Board within seven (7) days.

Please do not make any changes to the IRB approved consent without approval of the IRB. Only the IRB stamped approved consent should be used.

If your study meets the definition of a qualifying study that meets the FDAAA 801 definition of an "applicable clinical trial", you are responsible for ensuring that the trial has been registered properly on the Clinical Trials.gov website prior to the enrollment of any subject.

"Applicable clinical trials" generally include controlled clinical investigations, other than phase 1 clinical investigations (with one or more arms) of FDA-regulated drugs, biological products, or devices, that meet one of the following conditions:

- The trial has one or more sites in the United States
- The trial is conducted under an FDA investigational new drug application or investigational device exemption
- The trial involves a drug, biologic, or device that is manufactured in the United States or its territories and is exported for research

For complete statutory definitions and more information on the meaning of "applicable clinical trial," see Elaboration of Definitions of Responsible Party and Applicable Clinical Trial (PDF).

It is necessary that you utilize the assigned protocol number in any and all communication submitted to the IRB office, i.e. amendments, audits, etc.

This study has been renewed for an additional 1 year.